Essays in Applied Microeconomics

by

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Dissertation submitted in partial fulfillment of the requirements for the degree of
Doctor of Philosophy in the Department of Economics
in the Graduate School of Duke University
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Abstract

The essays in applied microeconomics contained within this dissertation examine prices in the developing economy contexts of Indonesia and the Philippines. Prices, observed and unobserved, are determined by and incentivize the behavior of all agents in the economy. Prices describe the interaction of individuals within a household and households within a market and reveal traits critical for development. Traits such as the efficiency of household resource allocations and the completeness of markets are analyzed in Central Java, Indonesia using a rich, longitudinal survey containing detailed price data used to estimate household demand systems. Unobserved, implicit prices of environmental goods are analyzed in the context of the Philippines. The valuation of environmental quality's implicit price is illustrated by comparing the health and human capital outcomes of the highly and least exposed. Exposure to environmental toxins can produce short and long-term damages to health and human capital reflecting undervaluation of the implicit price of environmental quality. The combined results of these essays on prices in development economics reveal allocation inefficiencies within the household and the economy and provide direction for development policy around the world.

To Ariel, the love of my life, for her boundless support.

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1

Introduction

Prices, observed and unobserved, are determined by and incentivize the behavior of all market participants. Among other characteristics, prices dictate individual and household patterns of consumption, demonstrate the availability of certain goods and describe the perceived value of goods. The prices of developing economies reveal individual, household and producer traits that are critical to development. The essays comprising this dissertation examine how individuals, households and producers interact as incentivized by observed and unobserved prices in developing economies.

The first essay of this dissertation, chapter 2, investigates how households respond to prices and what the responses tell us about household decision-making. Neoclassical economic theory produces predictions regarding the responses of individuals to prices and empirical studies often apply those theories and predictions to households. However, the application of individual utility theory to households requires strong assumptions that households either operate as dictatorships or each member of the household has identical preferences. Recent studies have widely rejected these strong assumptions, known as the unitary model, while supporting the characterization of household interactions based on the assumption of Pareto efficient resource allocations. Based on the assumption of Pareto efficiency, the collective model allows for heterogeneous preferences across members of the household and yields predictions regarding both variation in the distribution of income within the household and variation in local area prices. Examining this model and understanding whether household behavior is consistent with Pareto efficiency is critical for economic development. If a household member can be made better off without making anyone in the household worse off the sources of this friction must be identified and remedied. Very few tests of Pareto efficiency based on prices exist because of substantial data demands, however the detailed price data in the Work and Iron Status Evaluation was collected specifically for the purpose of testing Pareto efficiency of household resource allocations. Confirming previous studies, the results reject the unitary model, however evidence suggests that the collective model does not accurately represent household decision-making for larger households. These are important and novel results. Very few studies have used price variation to investigate household decision-making and this is one of the first that has rejected the hypothesis of efficiency. The results suggest that it is necessary to develop a better understanding of how markets work and the role that prices play in those markets.

Chapter 3 of this dissertation builds on chapter 2 again estimating household responses to prices using the Work and Iron Status Evaluation of Indonesia to determine how rural, farm households interact with their local markets. A potential deterrent to economic development is the incompleteness of markets. The vast major it of the literature on rural households and economic development is predicated on the assumption that markets are complete in the sense that all current and future markets exist. This assumption is both very strong and very powerful. Analyses of behavior are substantially simplified if markets can be assumed to exist. While previous literature has focused exclusively on the implications of complete markets for production decisions, this chapter defines and empirically tests an alternative prediction of complete markets for consumption allocations. The recursive property of the agricultural household model implies that, if markets are complete, production and consumption are linked only through an income effect. Therefore, if markets are complete then the prices of farm inputs affect consumption solely through an income effect and are weakly separable in demand. This weak separability implies a restriction on the marginal effects of input prices on consumption allocations that is examined using the detailed data from the Work and Iron Status Evaluation of Central Java, Indonesia that includes transaction prices for farm inputs and consumption goods collected in local shops and markets over a four-year period. The proposed test is free from a number of concerns plaguing work examining complete markets on the production side and the results suggest that separation between production and consumption decisions is not a valid characterization of the market environment in Central Java. Therefore, household responses to prices reveal that markets in Central Java, Indonesia are incomplete, a potential deterrent to economic development.

Unobserved prices also incentivize the behavior of market participants. This final chapter examines the implicit prices of environmental goods in a developing country. Economic development generally improves welfare, however economic activities can produce detrimental changes to the environment and market participants - potentially outweighing the benefits of development. Consumption and production processes which accompany and cause economic development employ and release to the environment tens of thousands of toxins, the vast majority with unknown effects to health and human capital. A priori whether the implicit prices of environmental goods are over, under or correctly valued is unclear. However, examining the effects to health and human capital of exposure to environmental toxins can indicate whether the environment's valuation is correct. In particular, the the undervaluation of the implicit price of environmental quality can be observed by comparing the uncompensated short and long-term health and human capital outcomes of the highly and least exposed. The aim of the research in this chapter is to improve the understanding of the effects to long-term health and human capital of fetal and early life exposures to multiple environmental contaminants in the developing country context of Metropolitan Cebu, Philippines. The Cebu Longitudinal Health and Nutrition Survey provides three decades of health and human capital data for individuals beginning in utero. Detailed meteorologic, topographic and infrastructure factors of transport enables the description of the toxin's path from the source to the individual and are employed as instrumental variables to identify the causal impacts of environmental exposures on health and human capital. Findings indicate that health and human capital in both the short and long-term are impacted by exposure to environmental toxins. The undervaluation of environmental quality's unobserved, implicit price in the context of this developing nation damages and human capital, precious commodities with observed value and prices.

In each of the chapters of this dissertation, Indonesian and Philippine prices enable the examination of market and environmental impacts on individual and household decisions. By describing the availability and value of goods, prices in these developing economies reveal undervaluation and allocation inefficiencies that are critical to economic development. The combined results of these essays on prices in development economics provide direction for economic development policy around the world.[1]

[1] The chapters of this dissertation comprise a significant portion of my research work while at Duke University. As scholarship is fundamentally a collaborative enterprise, these efforts have not been conducted in isolation. The work enclosed within the following pages has benefited from discussions and collaborations with both colleagues and advisors. Chapters 2 and 3 comprise a larger research agenda analyzing the production and consumption of agricultural households in Indonesia with Duncan Thomas, V. Joseph Hotz and Daniel LaFave. The analytical programs, writing, results, and any errors are solely my own.

2

Household Decision-Making: The Efficiency of Resource Allocation in Indonesian Households

2.1 Introduction

In spite of stringent requisite assumptions, many empirical studies apply the conclusions of individual utility theory to households. In effect, the application of individual utility theory to households requires either that households are assumed to operate as dictatorships or each individual in the household is assumed to have identical preferences. The results is the description of the household as equivalent to one individual, known as the unitary model, and while it is very convenient for empirical research many studies have rejected the required assumptions. Recent studies have supported an alternative model of the household, the collective model based on the assumption of Pareto efficient resource allocations. The collective model allows for heterogeneous preferences and treats the household as a multi-individual unit. This chapter investigates the household's decision process and tests the implications of both the unitary and collective models of households in Indonesia

In developing country contexts such as Central Java Indonesia, the setting of this study, where it is common to find many families living under the same roof and extended families living in close proximity to one another, it would seem improbable that households act as if they were one individual. Ethnographic studies, such as Tanner (1974), have described Indonesian society as being egalitarian with respect to the different sexes and the Indonesian household as a structure where "both men and women are important actors in the economic and ritual spheres," a description that, in the absence of identical preferences, appears at odds with the unitary model of the household. The results presented later confirm that single adult households operate as unitary households while many adult households do not. Additionally, evidence suggests that many adult households, in particular households with three or more adults, do not always operate as dictated by the collective model based on the assumption of Pareto efficient resource allocation, a result in contrast with previous studies.

Research on the decision-making of groups (such as households) has a long history in economics. Early attempts to model group behavior used community indifference curves. Leontief (1933) and Lerner (1934) use community indifference curves to model the behavior of nations involved in trade and Kaldor (1939) and Hicks (1939) argue that it is always possible to evaluate the effect of changes, such as tariffs and taxes, on the general welfare of groups through the use of community indifference curves. However, both De Scitovszky (1942) and Samuelson (1956) disprove this and point out the requisite assumptions in modeling group utility maximization. In particular, Samuelson (1956)[1] points out that the use of one indifference curve per group requires assuming either common preferences, a full set of perfectly enforceable state contingent contracts, or a dictatorial power structure. The model of group behavior under any of these assumptions is known as the unitary model.

[1] Also see Becker (1962, 1974, 1981)

More recent and less restrictive models of group behavior involving households include bargaining and collective models. Examples of the bargaining models can be found in Manser and Brown (1980), McElroy and Horney (1981) and Lundberg and Pollak (1993). Within these papers are interesting ideas leading to various descriptions and tests of household behavior. One of these ideas is that household demands are sensitive to the intra-household allocation of resources and to other influences in the decision process referred to by McElroy and Horney (1981) as threat point shifters. Another idea is that non-symmetric Slutsky matrices occur because household decisions cannot be adequately described by the unitary framework. Chiappori (1988) presents a general characterization of the household's decision process known as the collective model. Based solely on the assumption of a Pareto efficient allocation of household resources, this model generates testable implications and subsumes other household models as special cases. One of those special cases is the unitary model. Specifically, Browning and Chiappori (1998) show that if resources are allocated efficiently a household's demand responses to price changes can be characterized by the Pseudo-Slutsky matrix; the sum of a symmetric matrix and a matrix with rank equal to one less than the number of individuals in the household.

A characterization of how households operate is important not only for economic models and research but also regarding how to direct policy interventions. Various studies have looked at how policies directed at certain members of the household do not affect all household members equally (for example, see Thomas (1990), Schultz (1990), Bourguignon et al. (1993), Lundberg et al. (1997) and Duflo (2000)). This evidence suggests the presence of preference heterogeneity among household members, which begs the questions: if the household does not operate as if it were one individual then how many people in the household actually have a say in the decisions and how much, if any, cooperation exists? The effects of non-cooperative behavior within the household could impede efficiency as well as utility maximization. If households are inefficient then new models of their decision process must be developed based on different assumptions. And if Pareto efficiency is not achieved then determining why and directing policy to change this behavior could enhance social welfare.

While the rejection of the unitary model in empirical research is common, the majority of studies support the collective model. There are various types of tests of the unitary model ranging from symmetry of the Slutsky matrix to income pooling (after controlling for total income the distribution of income within the household should have no effect on household demand). Blundell et al. (1993) use a series of cross sectional surveys of British expenditure to estimate a demand system that rejects the symmetry of cross-price elasticities implied by the unitary model (see also Browning and Meghir (1991)). Browning and Chiappori (1998) introduce the collective model and perform tests of the unitary and collective models using Canadian expenditure data concluding that the unitary model performs well for single adult households but does not accurately represent the decision-making process for couples. Furthermore, Bourguignon et al. (1993) use French household expenditure data and reject the unitary model through a test of income pooling but provide evidence in support of the collective model. In developing countries these same tests of income pooling have also rejected the unitary model. Thomas (1990) uses survey data on family health and nutrition in Brazil to show that a mother's income has a disproportionately larger effect on the health of her family than that of the father. Schultz (1990) analyzes the effect of non-labor income on individual labor supply in Thailand and arrives at the same conclusion: a rejection of the unitary model. Additionally, using data from South Africa, Duflo (2000) shows that the gender of a recipient of an old age pension has an effect on a child's health and nutrition, again testing the income pooling hypothesis and rejecting the unitary model.

Studies regarding the Pareto efficiency of households, generally support the collective model with a few exceptions. Although Bourguignon et al. (1993) demonstrate that income pooling tests reject the unitary model their results also provide evidence in support of the collective model. Furthermore, after rejecting the unitary model's description of resource allocation in households of two adults Browning and Chiappori (1998) show that the resource allocations of 2 adult households are Pareto efficient. Two notable exceptions are Udry (1996) and Owens (2001). These studies indicate that the reallocation of land from women to their husbands would increase agricultural output of families in Burkina Faso and Senegal, respectively, leading to the conclusion that household resource allocation is not Pareto efficient. However, these results have been contested and other studies from the same areas have concluded that allocations are Pareto efficient. Akresh (2005) directly challenges the results of Udry (1996) concluding that only the regions of Burkina Faso studied by Udry (1996) exhibit Pareto inefficiency while all others in the country are efficient. Rangel (2004b) offers another challenge to Udry (1996) by positing that the presence of heterogeneous preferences does not preclude an efficient allocation of resources. Additionally, the results presented in Thomas and Chen (1994) as well as Rangel (2004a) demonstrate that intra-household allocations in Taiwan and Ghana, respectively, are efficient. More specifically regarding Rangel (2004a), a demand system of 10 goods is estimated for Ghanian households and the Pseudo-Slutsky matrix derived and tested for various household compositions. Despite somewhat mixed results for the collective model with multiple adult households, Rangel (2004a) does not reject the collective model.

This chapter presents tests of both the unitary and the collective models for households of various compositions and sizes in Central Java, Indonesia using a panel survey containing detailed price data. The methodology follows that of Browning and Chiappori (1998) and Rangel (2004a) which estimate demand systems for various types of households. Rich data from the Work and Iron Status Evaluation of Purworejo, Indonesia provides multiple waves of detailed household surveys and frequently collected price data. The variety of household compositions present in the data as well as location and time specific prices, and the detailed, disaggregated household expenditure data enable the estimation of demand systems for a wider variety of household types than Browning and Chiappori (1998). The panel structure of the data allows for the estimation of household fixed effects, as opposed to the multiple cross section data employed by Rangel (2004a). The use of household fixed effects identifies household responses to prices using unanticipated price variation, a distinction that explains the novel results of this study. Estimates of two demand systems - an eight good system and a 6 good system - are used to form the Pseudo-Slutsky matrix, the rank of which indicates the number of decision-makers in the household as well as the efficiency of resource allocations. The results confirm previous studies demonstrating that single adult households operate in the unitary framework but that larger households have more decision-makers and are not adequately represented by the unitary model. Similar to Rangel (2004a) mixed evidence is produced regarding the Pareto efficiency of resource allocations in two adult households. Furthermore, the results differ from previous studies regarding three or more adult households. Evidence suggests that in the context of Purworejo, Indonesia households with 3 or more adults do not exhibit Pareto efficient resource allocations. These results demonstrate that as the number of potential decision-makers present in the household increases the collective model becomes a less accurate representation of household decision-making.

The remainder of the paper proceeds as follows. Both the unitary and collective models and their testable implications are presented and discussed in section 2.2. Following this, section 2.3 will describe the estimation of the demand systems, the empirical implementation and execution of the tests of the collective model. Section 2.4 contains a discussion of the data, as well as a presentation of the estimation results and tests of the model. Section 2.5 concludes the paper.

2.2 Model

2.2.1 Theoretical Framework

Consider the following welfare function which flexibly combines the individual utility functions of J individuals:

$$W = W\Big(u^1(c^1, ..., c^J, G; \phi), u^2(c^1, ..., c^J, G; \phi), ..., u^J(c^1, ..., c^J, G; \phi)\Big) \tag{2.1}$$

G represents the public goods shared by each member of the household, c^j is the consumption vector of private goods for individual j and ϕ represents observable and unobservable characteristics of individuals in the household. From here, theoretical models of household behavior diverge due to different fundamental assumptions regarding behavior. In the unitary framework a household is viewed as a group of individuals that behave as one either due to common preferences, a full set of perfectly enforceable state contingent contracts or a dictatorial power structure. In the case of common preferences or dictatorial power structure the household welfare function assigns weight only to the utility of one member. The household decision problem in the unitary case is therefore represented as:

$$\max_C W = u^j(c^1, ..., c^J, G; \phi) \tag{2.2}$$

$$\text{st}: \; I = P' \cdot C = e$$

Let S be the total number of goods in the demand system, thus the dimension of the vectors P, C, c^j and G here is $S \times 1$. I is total household income, e total expenditure and P is a vector of prices. C, the total consumption of the household, is defined as:

$$\sum_{j=1}^{J} c^j + G = C \tag{2.3}$$

The inclusion of G, the public good, though excluded in some models, is benign since almost any good can be thought of has having some private and at least some public component. Income as a function of wages, w, time endowment, T, non-labor income, y^j, and maximized household production profits, π^*, as well as total household expenditure, e, are defined, respectively, as:

$$\sum_{j=1}^{J} (w^j T + y^j) + \pi^* = I \tag{2.4}$$

$$I = P' \cdot C = e$$

The collective model builds solely on the assumption of Pareto efficiency, making it a very general representation of household decision making.[2] Pareto efficiency, that there does not exist another resource allocation in which at least one individual is better off and no other individual worse off, is an assumption justified in the household context by the observation that interactions within the household can be viewed as a repeated game exhibiting the long run equilibrium of cooperation (see Browning and Chiappori (1998)). The model allows for preferences to be heterogeneous. The individual weights, $\mu_j(P, I)$, hereafter referred to as Pareto weights, associated with each individual's utility are zero-homogeneous functions of environmental factors (such as prices and income). Following Browning and Chiappori (1998) as well as Rangel (2004a), the collective model can be described as a weighted sum of household member's utilities subject to an income constraint.

[2] Chiappori (1988) also describes testable predictions of income effects

$$\max_C W = \mu_1(P,I)u^1(c^1,...,c^J,G;\phi) + \sum_{j=2}^{J} \mu_j(P,I)u^j(c^1,...,c^J,G;\phi) \tag{2.5}$$

$$\text{st}: \; I = P' \cdot C = e$$

This flexible framework creates a sequential approach to testing: first, test the special case - the unitary model - and, in the case of rejection, test the more flexible case - the collective model. More importantly, the assumption of Pareto efficiency in the collective model has been shown in Browning and Chiappori (1998) to produce a specific form of the Slutsky matrix thus providing a robust set of tests which exploit price variation.

2.2.2 Testable Predictions

A fundamental observable implication of utility theory - that the Hessian of the expenditure function, known as the Slutsky matrix, is symmetric and negative semi-definite - should hold for individuals as well as households that operate in a unitary fashion. However, the symmetry of the Slutsky matrix has been rejected in several studies using household data (refer to the discussion in the introduction regarding the studies performed by Blundell et al. (1993), Browning and Meghir (1991) and Browning and Chiappori (1998)). Besides symmetry, the unitary model also implies that the distribution of income within a household should not affect the household's demand for any particular good. This leads to the tests of income pooling that have been performed in studies such as Thomas (1990), Schultz (1990) and Duflo (2000). Each of these have rejected the unitary model of the household. Generalizing from the unitary framework we arrive at the collective model. According to the model, which begins with the assumption of Pareto efficiency, a matrix containing household demand responses to price changes will have a predictable form in spite of heterogeneous preferences within the household. This is the remarkable conclusion reached by Browning and Chiappori (1998). To see this, first consider the collective model and it's solutions: the Marshallian demand functions, ψ_s.

$$\max_C W = \mu_1(P,I)u^1(c^1,...,c^J,G;\phi) + \sum_{j=2}^{J} \mu_j(P,I)u^j(c^1,...,c^J,G;\phi) \tag{2.6}$$

$$\text{st}: \ I = P' \cdot C = e$$

$$\psi_s(P,e^*;\phi) = c_s(P,e^*,\mu(P,e^*);\phi) \tag{2.7}$$

e^* is the household expenditure at the optimal level of consumption, equal to income. Differentiating the demand functions with respect to a price change in good r, then breaking the derivative up into component parts and regrouping we see that the demand response is a function of the traditional substitution and income effects as well and a new component containing the impact of the Pareto weights.

$$\psi_{sr} = \frac{\partial\psi_s}{\partial p_r} + \frac{\partial\psi_s}{\partial e^*}c_r$$

$$\psi_{sr} = \left[\frac{\partial c_s}{\partial p_r} + \frac{\partial c_s}{\partial\mu}\frac{\partial\mu}{\partial p_r}\right] + \left[\frac{\partial c_s}{\partial e^*} + \frac{\partial c_s}{\partial\mu}\frac{\partial\mu}{\partial e^*}\right]c_r$$

$$\psi_{sr} = \left[\frac{\partial c_s}{\partial p_r} + \frac{\partial c_s}{\partial e^*}c_r\right] + \left[\frac{\partial c_s}{\partial\mu}\frac{\partial\mu}{\partial p_r} + \frac{\partial c_s}{\partial\mu}\frac{\partial\mu}{\partial e^*}c_r\right] \tag{2.8}$$

The first component from equation (2.8), $\left[\frac{\partial c_s}{\partial p_r} + \frac{\partial c_s}{\partial e^*}c_r\right]$, is the same as the elements of the traditional Slutsky matrix which reflects both a substitution effect due to the price change and the income effect due to the change in real income and expenditure. The second component from equation (2.8), $\left[\frac{\partial c_s}{\partial\mu}\frac{\partial\mu}{\partial p_r} + \frac{\partial c_s}{\partial\mu}\frac{\partial\mu}{\partial e^*}c_r\right]$, arises because of the Pareto weights. This component contains the resulting change in the attractiveness of the outside options due to the price change. For example, consider an Indonesian farm household made up of individuals with differentiated talents and preferences. Assume each individual has varying abilities in the production of different crops and each is responsible for producing the crop best suited to his or her abilities. The relative price increase of one good will make the happiness of the individual in charge of it's production relatively more important and, simultaneously and consequentially, increase the attractiveness of his or her options outside of the household. Alternatively, μ^j can be interpreted as pure income redistribution effects from intra-household lump sum transfers.

Following the previous formulation, the collection of the observed price responses will be defined as Ψ and called the Pseudo-Slutsky matrix with the traditional Slutsky price and expenditure component defined as Σ and the new income redistribution component defined as Ω. Recall that there are S goods.

$$\begin{bmatrix} \psi_{11} & \psi_{12} & \cdots & \psi_{1S} \\ \psi_{21} & \psi_{22} & & \\ \vdots & & & \\ \psi_{S1} & & & \psi_{SS} \end{bmatrix} = \Psi = \Sigma + \Omega \tag{2.9}$$

Utility theory shows that Σ must be a symmetric matrix but this does not mean the the observed price responses, Ψ, will be symmetric; a fact which explains the rejections of Slutsky matrix symmetry in the literature. Although Σ and Ω cannot be separately identified, the symmetry of Σ allows us to difference the observed price responses by their transpose and obtain an observable matrix, M, with testable implications.

$$M = \Psi - \Psi' = (\Sigma - \Sigma') + (\Omega - \Omega') = \Omega - \Omega' \tag{2.10}$$

The first testable implication is that under the unitary model $M = 0$ since Ω is

0. The unitary model implies first that Σ is symmetric, and therefore $(\Sigma - \Sigma') = 0$, and second that Ω is 0 because all but but of the Pareto weights are equal to 0 and do not change with changes to e^*. Therefore, the first step in addressing the households decision process is testing the null hypothesis that $M = 0$. A rejection of this hypothesis is a rejection of the unitary model.

Tests of the collective model utilize predictions regarding the rank of M. Essentially, if the rank of M is no more than two times the total number of household members minus one $(2 \times (J-1))$ then the collective model holds, or the household's resource allocations are Pareto efficient. From Browning and Chiappori (1998) the **SRk proposition** summarizes the implications of the collective rationality model:

PROPOSITION SRk: Consider a set of S goods. Assume that the household has $J = k+1$ members where $k < S-1$. In the collective setting the Pseudo-Slutsky matrix, Ψ, is the sum of a symmetric matrix, Σ, and a matrix of rank no greater than k (SRk, Symmetric plus Rank k).

Since Σ and Ω are not identified the SRk proposition also implies that, under the collective model, the matrix M is anti-symmetric $(M = -M')$ and it's rank is an even number. By the properties of matrix rank,

$$rank(M) \leq rank(\Omega) + rank(\Omega')$$

$$rank(M) \leq 2 \times rank(\Omega)$$

$$rank(M) \leq 2 \times (J-1) = 2 \times k$$

In summary, tests following this order are employed:

i) M's symmetry or equality with zero is tested. If rejected the unitary framework is ruled out.

ii) M's rank is tested for even values. If $rank(M) > 2 \times (J-1)$ then the collective model is rejected.

2.3 Empirical Implementation

2.3.1 Estimation of the Demand System

In this section the flexible functional form used to estimate the demand system is described flowed by the methods used to test the statistical rank of the Pseudo-Slutsky matrix.

Previous research has generally employed the Quadratic Almost Ideal Demand System (QUAIDS) as parameterizations of the Working-Leser demand system (see Browning and Chiappori (1998) and Rangel (2004a)). QUAIDS imposes a quadratic structure on the relation between the log of per capita expenditure and the budget share for each good however it is preferable to use less parametric functional form. While Working-Leser curves are well grounded in theory, a limitation of the model is its imposition of a linear form for the relationship between the log of per capita expenditure and the budget share for each good. This functional form has the disadvantage of being prone to influential observations in the extreme values of PCE, and forces a linear relationship where it may not be appropriate.[3] To address this concern, a piece-wise linear function of PCE is used to allow the demand functions to have a more flexible shape and limit the influence of extreme values. Let $S_l(ln(e))$ be the l'th piecewise linear function of the log of per capita expenditure, then:

$$\tilde{c}_s = \alpha_s + P'\delta_s + \beta_{s1}S_{s1}(ln(e)) + \beta_{s2}S_{s2}(ln(e)) + ... + \beta_{sl}S_{sl}(ln(e)) + \epsilon \qquad (2.11)$$

The parameters of interest are the δ_s's. Let Δ be the $S \times S$ matrix of log price coefficients and δ_s' is a row in Δ, or,

[3] This issue is true for other parametric demand specifications including the Almost Ideal Demand System (Deaton, 1988).

$$\Delta = \begin{bmatrix} \delta_1' \\ \delta_2' \\ \vdots \\ \delta_S' \end{bmatrix} = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1S} \\ d_{21} & d_{22} & & \\ \vdots & & & \\ d_{S1} & & & d_{SS} \end{bmatrix} \tag{2.12}$$

These are the observed price response coefficients which will be used to test the implications of the unitary and collective models. It is important to note that Δ is not equivalent to $\Psi = \Sigma + \Omega$ or to $M = \Omega - \Omega'$ but, as established by Browning and Chiappori (1998), M is SRk if and only if Δ is SRk.

Homogeneity is imposed and adding up is implied by the data construction. A numeraire good is chosen and used to normalize all other prices by the price of this good.[4] In a system of S goods and 1 numeraire good, $S-1$ systems of equations are estimated and the matrix Δ is $(S-1) \times (S-1)$ in dimension. The population is divided into various groups depending on the number of potential decision-makers within the household - one, two and three or more - and the demand system is estimated for each group. Grouping by household composition allows the tests to compare the actual number of decision-makers within household to the number of potential decision-makers, rather than describing sample wide averages.

2.3.2 Implementation of the Tests

To test the unitary model M's symmetry or equality with zero must be tested and to test the collective model the rank of M must be determined and tested. While testing $M = 0$ is straightforward, testing the rank of M is complicated. The rank of deterministic matrices is found by counting the number of linearly independent columns/rows by getting the matrix into row reduced Echelon form or performing a singular value decomposition and counting the number of non-zero diagonal elements.

[4] For the purposes of this paper, the good selected as the numeraire is "Home Rent". This is done because the quantity is non-zero for all survey respondents and the price is recorded in all instances as either the monthly amount paid or the amount that would be paid if rent were required. Further discussion of this and other goods in the demand systems will follow.

When the elements of the matrix are estimated with variance determining the rank becomes difficult.

However, as indicated, the symmetry or equality with zero of M is necessarily the first test. As demonstrated by Blundell and Robin (1999) the price response coefficients are asymptotically normal and because M is a linear combination of the demand system parameters as $\sqrt{n}$ approaches infinity the estimated $\hat{M}$ approaches M with variance V.

$$\sqrt{n} \cdot vec(\hat{M} - M) \rightarrow N(0, V) \tag{2.13}$$

The following is a description of the joint test of $M = 0$. Because the upper and lower elements are the same in absolute value, $\frac{(S-1)\times S}{2}$ elements of M are tested for equality to 0. The construction of the joint test yields the following Wald statistic with $w_1 = \frac{(S-1)\times S}{2}$ degrees of freedom:

$$Wald_{symm} = \left[Rvec(\hat{M}) \right]' \left[RVR' \right]^{-1} \left[Rvec(\hat{M}) \right] \rightarrow \chi^2_{w_1} \tag{2.14}$$

R is a selection vector and V is the variance-covariance matrix of the elements in $\hat{M}$. The results can be sensitive towards under rejection if a large enough set of goods is employed. The current study will test both an 8 and a 6 good demand system.

If the test of $M = 0$ is rejected then the collective model based on Pareto efficient resource allocations will be alternatively tested. There is a large literature of methods to determine rank and this study will employ three of them: the Browning and Chiappori (1998) linear combination test, the Bullock (1995) bootstrapped borderline singular value test, and the Ratsimalahelo (2003) asymptotic distribution of singular values test.[5]

[5] Other methods are described in Gill and Lewbel (1992), Cragg and Donald (1996) and Robin

Browning and Chiappori (1998) linear combination test:

Browning and Chiappori (1998) show that M having 2 linearly independent columns/rows is equivalent to testing:

$$h(m_{sr}) = m_{sr}m_{12} - m_{1s}m_{2r} + m_{1r}m_{2s} = 0 \qquad \forall \quad r > s > 2 \tag{2.15}$$

This results in $w_2 = \frac{(S-2)\times(S-3)}{2}$ restrictions and the following non-linear Wald statistic:

$$Wald_{BC} = h(m_{sr})' \left[\frac{\partial h}{\partial m_{sr}} V \frac{\partial h}{\partial m'_{sr}} \right]^{-1} h(m_{sr}) \rightarrow \chi^2_{w_2} \tag{2.16}$$

A caveat of in the use of Wald statistics to test non-linear hypothesis is the widely discussed non-invariance of the test statistics to reformulations of the null hypothesis.[6] Moreover, this statistic is subject to Type II errors implying that the tests of the hypothesis that the rank of M is less than or equal to 2 are likely to fail to reject even if the hypothesis is false. Additionally, this test is that it only works when testing $H_0 : rank(M) \leq 2$. Understanding the allocations of larger households is critical to this study so the inability to examine higher rank hypotheses with this test is corrected for by the use of the next two tests described below.

Bullock (1995) bootstrapped borderline singular values test:

The bootstrapped borderline singular value test from Bullock (1995) tests the equality with zero of the borderline singular value that should be zero under the null hypothesis in each bootstrapped matrix $\hat{M}_b$. Denote the full sample estimate of M as $\hat{M}$. Also denote the bootstrapped estimates of M as $\left\{ \hat{M}_b \right\}_{b=1}^{B}$. The singular values

and Smith (2000).

[6] See Gregory and Veall (1985), LaFontaine and White (1986), and Philipps and Park (1988). See also Dagenais and Dufour (1991).

of each bootstrapped estimate can be easily obtained and will be denoted $\left\{\hat{D}_b\right\}_{b=1}^{B}$. The borderline singular value is the singular value that should be zero if the null hypothesis is true. For example, consider the hypothesis $H_0 : rank(M) \leq r = 2$. If the null hypothesis holds then M should have two non-zero singular values. Since the singular value decomposition arranges the singular values on the diagonal in descending order the borderline singular value that should be zero under the null is placed in the $r+1$ position - in the case of the null hypothesis $rank(M) \leq r = 2$ it is the element $(3,3)$ in $\hat{D}_b$. Let the set of borderline singular values be denoted as $\left\{\hat{d}_{b,r+1}\right\}_{b=1}^{B}$ and $\bar{M}$ be the mean of the bootstrapped estimates of M. A and B denote the matrices flanking the singular value matrix D in the singular value decomposition: $M = ADB'$.

Essentially, the test creates cutoff values for the borderline singular value such that values less than the cutoff provide evidence in support of the null hypothesis. The construction of the cutoff values begins with the singular value decomposition of $\bar{M} = \bar{A}\bar{D}\bar{B}'$. Next D^* is defined as $\bar{D}$ except that the $S - r$ smallest singular values are substituted by zeros. This leads to $M^* = \bar{A}D^*\bar{B}'$. Finally, the matrix that will give the cutoff values is:

$$M_b^H = M^* + \left[\hat{M}_b - \bar{M}\right] \tag{2.17}$$

There is an M_b^H for each bootstrap and the decomposition of each of these yields the constructed cutoff singular values, $\left\{\hat{d}_{b,r+1}^H\right\}_{b=1}^{B}$. From this the p-value of the test is defined:

$$p_{BSSV} = \frac{1}{B}\sum_{b=1}^{B} 1\left\{\hat{d}_{b,r+1}^H > \hat{d}_{b,r+1}\right\} \tag{2.18}$$

A potential issue for this test is a size distortion due to the fact that singular values are not pivotal statistics. Size distortion is also a potential problem for the asymptotic distribution of singular values test presented next.

Ratsimalahelo (2003) asymptotic distribution of singular values test:

As with the previous test, the construction of the Ratsimalahelo (2003) asymptotic distribution of singular values test statistic begins by obtaining the singular values. However, only the singular values of the full-sample estimated $\hat{M}$ are required.

$$\hat{M} = \hat{A}\hat{D}\hat{B}' \tag{2.19}$$

Pre-multiplying by $\hat{A}'$ and post-multiplying by $\hat{B}$ yields the following:

$$\hat{D} = \hat{A}'\hat{M}\hat{B} \tag{2.20}$$

The estimated $\hat{M}$ is now defined as a deviation from the population value M such that as the number of observations in the sample increase the deviation from the true population value goes to zero. In the following equation H is defined as $\frac{\hat{M}-M}{\epsilon}$ and $\epsilon = \frac{1}{\sqrt{n}}$.

$$\hat{M} = M + \epsilon H \tag{2.21}$$

From the consistency of $\hat{M}$ the rate of convergence to zero of ϵH is $O_p(\frac{1}{\sqrt{n}})$.

Considering the $(S-r)\times(S-r)$ sub-matrix of $\hat{D}$ that, under the null hypothesis, should be zero

$$\hat{D}_2 = \hat{A}_2{}'\hat{M}_2\hat{B}_2 \tag{2.22}$$

both $\hat{A}$ and $\hat{B}$ can be shown to be:

$$\hat{A}_2 = \tilde{A}_2 + O_p(\frac{1}{\sqrt{n}}) \tag{2.23}$$

$$\hat{B}_2 = \tilde{B}_2 + O_p(\frac{1}{\sqrt{n}}) \tag{2.24}$$

$\tilde{A}_2$ and $\tilde{B}_2$ are derived through the post-multiplication of A_2 and B_2 by general orthogonal matrices. As a result, the following equation describes the asymptotic properties of $\hat{D}_2$:

$$\hat{D}_2 = \tilde{A}_2 \hat{M} \tilde{B}_2 + O_p(n^{-1}) \tag{2.25}$$

Furthermore, because singular value matrices are invariant to both pre- and post-multiplication by orthogonal matrices:

$$\begin{aligned} \hat{D}_2 &= \tilde{A}_2(M + \epsilon H)\tilde{B}_2 + O_p(n^{-1}) \\ &= D_2 + \epsilon A_2' H B_2 + O_p(n^{-1}) \end{aligned} \tag{2.26}$$

This results indicates that, similar to $\hat{M}$ in equation (2.21), as the number of observations increase towards infinity the estimated sub-matrix of singular values $\hat{D}_2$ approaches D_2 with a variance of $Q = (B_2 \otimes A_2')V(B_2 \otimes A_2)$.

$$\sqrt{n} \cdot vec(\hat{D}_2 - D_2) \to N(0, Q) \tag{2.27}$$

The inverse of Q is calculated using the Moore-Penrose pseudo inverse and the constructed Wald statistic follows as:

$$Wald_{ADSV} = n \cdot vec(\hat{D}_2)' \cdot Q^{-1} \cdot vec(\hat{D}_2) \to \chi^2_{min\{(S-r)\times(S-r), rank(V)\}} \tag{2.28}$$

2.3.3 Estimation Issues

The following issues are concerns of the demand estimation strategy and will be discussed here: sub-aggregation, separability and endogeneity.

In order to more closely approximate a complete demand system with reasonable separability assumptions (discussed below) the estimated goods are actually sub-aggregates. Two demand systems of eight and six goods are estimated and their Psuedo-Slutsky matrix predictions tested. The 8 good demand system is composed of 4 food and 4 non-food sub-aggregates: grains, fruits and vegetables, protein, high calorie foods, tobacco, home goods, rent and human capital. The 6 good demand system is composed of 3 food and 3 non-food sub-aggregates, combining proteins and high calorie foods into one sub-aggregate good, and combining home goods and rent into one sub-aggregate good representing housing expenditure. Each sub-aggregate good is composed of multiple, individual goods. For example, the grain sub-aggregate good is composed of, among other things, rice, noodles, flour and nuts. Protein is composed of beef, chicken, fish, tofu and eggs. A full description of each good within the sub-aggregate classifications of both demand systems is given in table A.1 of this chapter's appendix. Corresponding prices for each sub-aggregate good are weighted averages of the component goods. A complete description of the prices composing each composite price for each demand system is given in table A.2 of this chapter's appendix.[7] Additional tables in the appendix display the estimated demand for the 8 good system and the accompanying tests of the matrix rank, while the main tables displayed utilize the 6 good demand system. The emphasis on the smaller demand system is because of power which diminishes as the number of goods in the demand system increases. However, insight regarding tests of higher rank are gained from the larger demand system.

[7] The weights are derived from a comprehensive, contemporary survey of consumption in Indonesia, SUSENAS.

The goods in the demand system are assumed to be separable from both the labor/leisure decision and intertemporal allocation decisions. Past research has employed different separability assumptions and addressed them by limiting the sample; Browning and Chiappori (1998) limit their sample to only include single adults and couples living alone that are also labor force participants and Rangel (2004a) limits to only include farm households. In the context of Central Java, Indonesia these additional limitations would be arbitrary and would not provide additional validity to the estimates. First, labor force participation is more difficult to define in an area with high levels of household production and employment is more fluid. Second, although about half of the households in the sample do not have farm land many of them are related to households with farms and contribute to farm production so to classify them as non-farm households is not very clean. The separability of intertemporal allocations is an area of very interesting future research, however the current study will continue to adopt the assumption of separability.

There are at least three potential sources of endogeneity which could affect the validity of the above estimation approach. One potential source of endogeneity is grouping. Grouping based on household size and composition may be endogenous to the decision process but the benefits to stratification outweigh the potential costs. Without grouping, the theoretical prediction of the rank of the Pseudo-Slutsky matrix cannot be used and little can be said regarding the efficiency of the household's allocations. Additionally, because many households in the survey are producers, prices have the potential to be endogenous. However, this is not likely to be a problem for two reasons: competitive markets and price construction. The vast majority of households produce rice and other farm products which are part of a competitive market where producers have minimal ability to affect prices. Furthermore, the prices used in estimation are medians specific to time and place, eliminating outlying prices. Finally, in the household fixed effects model, the price response coefficients are identified off unexpected price variation. Because of these reasons, the prices used in estimation are unlikely to be endogenous.

Furthermore, household expenditure is likely endogenous for at least two reasons. First, unusually high or low expenditure on a good by the household will affect both the error and the total expenditure, thereby inducing a correlation between expenditure and the error. The structure of the data allows for the various types of goods to be either aggregated or disaggregated in order to reduce the lumpiness of purchases. First, food purchases are likely to be less lumpy and they are aggregated from weekly consumption to monthly. Then, data on more durable goods are collected for either the past month or the past year, making the presence of zeros in expenditure less likely. Other studies have used net income to instrument for the potential correlation between expenditure and the errors. However, since net income is a function of the labor/leisure decision it may also be correlated with the error term in the demand equation. The second reason that expenditure may be endogenous is the endogeneity of the sale and production of household goods (from the farm or otherwise). The level of complexity increases exponentially when incorporating these features into the model. Since farming is a multi-period process with uncertainty, intertemporal allocations as well as risk would become issues in a model incorporating profit maximization of household profits. Also, the choice of crops in a multi-crop environment, the types and intensity of inputs to use as well as investment in technology would either be features of the model or require assumptions about producer behavior. This is an area of fruitful future research however for the purposes of the current paper household expenditure is assumed to be exogenous.

2.4 Results

2.4.1 Data

In order to estimate the demand system as presented in the models above, detailed consumption and expenditure data as well as price data with sufficient variation are needed. The household panel survey known as the Work and Iron Status Evaluation, or WISE, is an extensive survey of households and communities including detailed household expenditure data as well as location and date specific prices. WISE is a random-assignment treatment and control intervention in Central Java Indonesia, specifically the Purworejo District, designed to document the extent of iron deficiency in Central Java and show the effects to physical health and labor market outcomes of randomly selected individuals given iron supplements. experience.[8]

Purworejo is located on the southern coast of Java in Indonesia and is home to about 1 million people. As seen in table 2.1, the majority of households in the sample live in rural areas. 46% of single adult households live in rural areas but for all other household types over 75% of them are rural. Approximately 18,000 respondents living in 4,500 households were selected for the study sample. Starting in early 2002 with the pre-baseline survey each household was resurveyed every four months for nearly three years until 2005. Additionally follow-up surveys were conducted in 2007 and 2009. Following the screening, 99.6 percent of the selected households participated in the pre-baseline survey. Almost 97 percent of households in the baseline survey were resurveyed in the following wave. Analysis of the relation between observable characteristics and attrition shows that slightly more men attrit than women and attrition is more likely during young adulthood than any other time.

A demographic description of the three household types - single adult households,

[8] For additional information regarding the WISE survey see Causal Effect of Health on Labor Market Outcomes: Evidence from a Random Assignment Iron Supplementation Intervention by Thomas et al. (2011).

two adult households, and households with three or more adults - is provided in table 2.1. The households are described by composition, age, location and education. Additionally, the average log per capita total expenditure by group is given as well as the average number of households in each wave and the total number of households of each type. The average household size for single adults is 1.39, showing the presence of children in the homes of single adults. The average size of 2 adult homes is 2.91 and for 3 or more adult homes the average size is 4.57 individuals. The large majority of households have multiple adults and households with 3 or more adults are more common than 2 adult households. The heads and spouses of 2 and 3 or more adult households have on average more years of education than the heads of single adult households and the per capita expenditure of single adult households is much higher than multiple adult households. Each household is followed throughout the course of the longitudinal survey allowing for the estimation of household fixed effects in the demand system.

Table 2.2 describes the average budget share allocations.[9] Again, the largest differences seen in this table appear to be between singles and all other groups, most notably in regards to food. Single adult households devote much more of their budget to high calorie foods (mainly prepared foods) than all other groups and less of their budget share to grains. Additionally, single adult households spend more on rent than multiple adult households likely a larger percentage of single adult households reside in urban areas as seen in table 2.1. However, the overall allocation between food and non-food items is not much different among groups.

The price surveys of the Work and Iron Status Evaluation were administered every three months, recording prices of many goods including rice, cassava, oil, sugar, chicken, gas, household goods, farm equipment, clothes and many others. Every

[9] As mentioned, see table A.1 of this chapter's appendix for details regarding the composition of the sub-aggregates goods.

attempt was made to obtain prices for the same brand, quality and size, and when they are not available close substitutes are identified and used. Prices in WISE therefore have low quality variation and few missing values (see McKelvey (2011) for a very thorough treatment of the potential pitfalls to quality variation in price data). Prices, as previously mentioned, are constructed first as weighted averages of the various component goods of the 8 and 6 sub-aggregates - grain, fruits and vegetables, protein/high calorie foods, tobacco, home goods/rent, and human capital. Additionally, the median price specific to time (date when the household was interviewed) and place (enumeration area) is used in order to eliminate potential measurement error and outliers. Finally, the prices are normalized by the price of a numeraire good, which in this case is the rent of the household's home. The average normalized composite prices and their variation across communities and waves is presented in table 2.3.[10] Notice that for the 8 good demand system the prices of 7 goods are shown because one, the rental price, is the numeraire and the same goes for the 6 good demand system in the bottom half of table 2.3 which shows the prices of 5 goods.

2.4.2 Estimated Demand System

The demand system from equation (2.11) is estimated using the method of seemingly unrelated regressions with $S - 1$ equations (5 for the 6 good demand system). In order to preserve the power of the estimation all observations in the dataset are used and each group (single adults, two adults, two adults and others and many adults) is distinguished by an indicator variable.[11] Also, since each household is included multiple times in the data the standard errors are corrected for clustering by household.

[10] As mentioned, see table A.2 in the appendix of this chapter for details regarding the composition of the sub-aggregates prices.

[11] Robustness checks to this estimation strategy have been performed, namely the estimation of the demand system using only observations of the particular household type. The resulting tests of the Pseudo-Slutsky matrix are largely unchanged.

Furthermore, each equation in the system has the same control variables: district fixed effects (district being larger than the enumeration areas to which the prices are specified), household composition including how many adults, elders and children are in the home, education levels of the male and female heads of the household, the age of the heads of household and indicators of whether the household resides in an urban or rural location. Additionally the demand systems are estimated with controls for household composition as well as household fixed effects - effectively controlling for the time invariant unobservable household level determinants of demand and the change in household composition over time. However, in order to approximate conditions under which previous studies have estimated the Pseudo-Slutsky matrix and performed tests of the unitary and collective models the demand systems have also been estimated without household fixed effects. Moreover, in order to eliminate any time trends and to make the prices equivalent to real prices wave fixed effects are included in the estimation.[12]

The estimated 6 good demand systems for both single adult and multiple adult households (multiple including 2, 3 and more adults in the household) is displayed in table 2.4. The results for the larger demand system are shown in table A.5 of the appendix. Table 2.5 repeats table 2.4 but further subdivide the household types into single adult households, 2 adult households and 3 or more adults households (table A.6 of the appendix is the same for the larger demand system). Each of the estimated demand systems in these tables share similarities in regards to their uncompensated own-price elasticity estimates. The estimated uncompensated own-price elasticities of non-food goods are, for the most part, negative and precisely estimated. The few which are not negative are not precisely estimated and not significantly different from zero. This result for non-food goods is as expected however some of the un-

[12] Additional robustness checks have been performed using real prices with season and year fixed effects. As with previously mentioned robustness checks the resulting tests of the Pseudo-Slutsky matrix are largely the same.

compensated own-price elasticities of food goods are positively signed. Most of these coefficients are imprecisely estimated and not significantly different from zero, however the coefficient for grains is consistently positive and significantly different from zero. This uncommon result is likely due to household production, in particular the large number of farm households in the survey. Individual goods which compose the sub-aggregate goods of fruits and vegetables, protein and high calorie are not often produced by the household however grains, in particular rice, is the most common crop grown in the region of Purworejo, Indonesia. The increase in the price of the farm's output good includes a profit effect that is absent from the demand system. Therefore, it is likely that the positive own-price elasticity of grain is the result of the increase in farm revenue when the price of rice increases.

2.4.3 Pseudo-Slutsky Tests

As previously described, tests of the Pseudo-Slutsky matrix proceed first by examining the symmetry or equality with 0 to test the unitary model and then, upon rejection of the unitary model, continue to test the rank of the matrix and the collective model. Each of the tables 2.6, 2.7, 2.8 and 2.9 contain the results of the unitary model test in the top panel and the results of the three rank tests of the collective model in the bottom panel (corresponding tables for the larger, 8 good demand system are displayed in the appendix, tables A.7, A.8, A.9, and A.10). For the test of the unitary model both the Wald statistic and the corresponding p-value are given. For the first test of the collective model, the Browning and Chiappori (1998) linear combination test of $rank(M) \leq 2$, both the Wald statistic and the corresponding p-value are displayed. The second test of the collective model, the Bullock (1995) borderline singular value test, does not produce a statistic and therefore only displays the p-value. The third test of the collective model, the Ratsimalahelo (2003) asymptotic distribution of singular values test, produces both a Wald statistic and a corresponding p-value. Both the borderline singular value test and the asymptotic distribution of singular values test are performed on the estimated M matrix testing both null hypotheses of $rank(M) \leq 2$ and $rank(M) \leq 4$.

In table 2.6, the price response coefficients of the 6 good demand system with household fixed effects are estimated and the resulting rank of matrix M is tested.[13] The first thing to notice is the joint test of symmetry for single adult homes. The null hypothesis of symmetry is not rejected for single adult homes with a Wald statistic of 9.90 and a p-value of .45. Not rejecting the symmetry of the Pseudo-Slutsky matrix for a single adult home aligns with both intuition and the predictions of utility theory. However, the unitary model is handily rejected for homes with multiple adults as expected. This confirms the intuition that homes with multiple potential decision-makers do not act as one individual. Having rejected the unitary model of the household the collective model of the household is next to be tested. And despite not rejecting the unitary model for single adult households the results of the collective model tests for these households will still be examined. However, despite not rejecting the unitary model for single adults it is rejected for multiple adult households.

Proceeding to the tests of matrix rank which correspond to tests of the collective model, for the Browning and Chiappori Linear Dependence Test of $H_0 : rank(M) \leq 2$ we cannot reject the null hypothesis for single adult homes but for non-single adult homes the null hypothesis is again rejected. The rank of M corresponds intuitively with the number of decision-makers in the home, thus the test provides evidence that there are two or fewer decision-makers in the single adult home and more than two decision-makers in the non-single adult home. Additionally, the null hypothesis

[13] As a result of the contracted demand system, the asymptotic distribution test of $rank(M) \leq 4$ can no longer be performed due to very limited degrees of freedom (4). Nevertheless, the test of $rank(M) \leq 4$ can still be performed by the borderline singular value test which does not produce a statistic with certain degrees of freedom.

implies Pareto efficiency so we cannot reject the conclusion that allocations within the single adult home are Pareto efficient. However, a similar statement regarding Pareto efficiency cannot be made of multiple adult homes. Each of the other tests, the borderline singular value test and the asymptotic distribution of singular values test, produce similar results for single and multiple adult households. The borderline singular value test of $rank(M) \leq 2$ again produces evidence that the collective model does not accurately describe multiple adult households however the test of $rank(M) \leq 4$ does not reject the null for multiple adult households implying that the number of decision-makers in these households is less than or equal to 4. Similarly, the test of the asymptotic distribution of singular values does not reject the collective model for single adult household while the collective model is rejected.

When these same tests are performed using demand system estimates without household fixed effects the results continue to reject the unitary model of the household. However the rejection of the collective model for multiple adult households is less clear. These results are presented in table 2.7. The results from the price response matrix of the 6 good demand system are very mixed. These mixed results provide some insight into why previous studies have not rejected the collective model of the household in describing the resource allocations of multiple adult households. Previous studies have not employed a rich, panel dataset and the accompanying household fixed effects which absorb unobservable, time-invariant determinants of household demand.

What remains to be discovered is which types of households are driving the rejection of the collective model for multiple adult homes. The study adopts a simple division of household types - single adult households, 2 adult households and 3 or more adult households. Intuition would suggest that the larger the number of potential decision-makers in the household the less likely the allocations will be Pareto efficient. This intuition is confirmed as the results suggest that the type of households which drive the rejection of the collective model for multiple adult households are those with 3 or more adults present.

Table 2.8 presents tests of the unitary and collective models of the household using price responses estimated in a 6 good demand system including household fixed effects for single, 2 and 3 or more adult households. As with previous results the unitary model is not rejected for single adult households but is rejected for both 2 an 3 or more adult households. Regarding the collective model, both the linear combination test and the asymptotic distribution of singular values test reject the null hypothesis that $rank(M) \leq 2$ for 2 adult households. However, while the borderline singular value test does not reject the null for 2 adult households it does reject the null for households of 3 or more adults. Similarly, the Wald statistics of both the linear combination and asymptotic distribution tests illustrate that the case for rejection of the collective model grows stronger as the number of adults in the household increase. As a result, it is clear that the household type which drives the rejection of the collective model for multiple adult households in the context of Purworejo, Indonesia are households with 3 or more adults.

Table 2.9 repeats table 2.8 using demand system estimates that do not include household fixed effects. As usual, the results are clear for the unitary model - it does not accurately describe non-single adult households. However, without household fixed effects none of the tests reject the collective model for 2 and 3 or more adult households. These results align well with previous examinations of the collective model, namely Rangel (2004a), which employ cross sectional data and do not reject the collective model for households of many adults. It seems apparent that unobservable, time-invariant determinants of household demand bias the estimates towards more cooperative appearing resource allocation. Therefore, when unanticipated price variation is used to identify the demand system, as in the case of the household fixed effects model, the results indicate that allocations are not Pareto efficient and households are not fully cooperative. Further analysis is needed to examine the sources of household allocation inefficiency and to derive policies to alleviate and generate welfare improvements.

2.5 Conclusion

Households in the developing world, where multiple adult households are prevalent, are complicated structures. Understanding how households operate is important not only for accurate economic models and research but also to know how to direct policy interventions. This paper addresses both the unitary and collective models for households and extended families. The evidence indicates that single adult households are accurately described by the unitary model while larger households are not. This is consistent with the majority of past research regarding the unitary model.

However, with few exceptions, prior research has supported the collective model of the household while the tests presented within this paper reject the Pareto efficiency of resource allocations within multiple adult households, particularly households of 3 or more adults. Udry (1996) and Owens (2001) cite apparent gender discrimination leading to the inefficient allocation of resources within households. Due to the format of the tests presented in this paper the reasons for the inefficient allocation of resources within the households less apparent, however the analysis of different size demand systems as well as the contrast between estimates including and not including household fixed effects give an explanation for previous results which do not reject the collective model for many adult households. When household fixed effects are included to absorb unobservable time-invariant determinants of household demand the tests of the Pseudo-Slutsky matrix reject the Pareto efficiency of resource allocations within the household. Without the fixed effects the rejection of the collective model for multiple adult households is less strong indicating that that unobservable, time-invariant determinants of household demand bias the estimates towards more efficient appearing resource allocations.

2.6 Tables

Table 2.1:

Descriptive Statistics

	Single Adult	2 Adults	3+ Adults
Demographics:			
Men 15-64	0.23	0.72	1.50
	(0.48)	(0.50)	(0.81)
Women 15-64	0.39	0.85	1.44
	(0.47)	(0.44)	(0.70)
Men 65+	0.14	0.26	0.30
	(0.29)	(0.44)	(0.46)
Women 65+	0.29	0.19	0.30
	(0.39)	(0.40)	(0.47)
Kids 0-14	0.32	0.88	1.04
	(0.69)	(1.03)	(1.03)
Household Size	1.39	2.91	4.57
	(0.79)	(1.06)	(1.37)
Household Head Age	60.00	53.50	54.81
	(18.71)	(15.38)	(12.69)
Spouse Age		46.84	48.72
		(14.75)	(11.60)
Household Head Education (Yrs)	4.65	6.65	6.50
	(4.55)	(4.43)	(4.08)
Spouse Education (Yrs)		5.96	5.63
		(4.36)	(3.96)
Rural Household (%)	72	80	78
Farm Household (%)	44	75	82
Expenditure (Rp/1000):			
Total Household Per Capita Exp.	411.69	279.90	218.80
	(384.83)	(251.49)	(181.80)
Sample:			
Average N. Households Per Wave	446	2161	2697
Total N. Households	4010	19448	24271
Total N. Waves	9	9	9

Table 2.2:

Budget Shares

	Single Adult	2 Adults	3+ Adults
Composite Goods (6):			
Grain	13.48	15.96	17.13
	(10.27)	(8.79)	(9.01)
Fruit and Vegetable	6.28	7.17	6.81
	(5.16)	(4.51)	(4.22)
Protein and High Calorie	35.81	33.41	31.40
	(14.80)	(11.80)	(10.83)
Tobacco	3.15	5.27	5.69
	(6.25)	(6.54)	(6.40)
Human Capital	14.55	16.36	19.46
	(13.45)	(12.66)	(12.59)
Housing	26.73	21.84	19.51
	(11.14)	(9.36)	(8.30)
Total Food and Non-food Shares:			
Food	58.73	61.80	61.03
	(15.39)	(13.95)	(13.45)
Non-Food	41.27	38.20	38.97
	(15.39)	(13.95)	(13.45)
Number of Observations	4010	19448	24271

Table 2.3:

Composite Prices

	Single Adult	2 Adults	3+ Adults
Composite Prices (Rs10,000) (6 Goods):			
Grain	0.54	0.53	0.52
	(0.15)	(0.14)	(0.13)
Fruit and Vegetable	0.76	0.74	0.73
	(0.21)	(0.20)	(0.19)
Protein and High Calorie	4.92	4.79	4.71
	(1.12)	(1.05)	(0.99)
Tobacco	0.43	0.42	0.41
	(0.06)	(0.06)	(0.06)
Human Capital	1.79	1.77	1.76
	(0.22)	(0.22)	(0.21)

Table 2.4:

Demand System (6 Goods) Estimates

	Grain	Protein and High Calorie	Fruits and Vegetables	Tobacco	Human Capital
Single Adult Households					
Log of Composite Prices					
Grain	2.71	4.67	2.11	2.68	-11.68**
	(4.52)	(6.18)	(2.36)	(2.37)	(5.48)
Protein and High Calorie	-15.00**	1.32	7.66**	13.53***	-5.08
	(7.08)	(9.69)	(3.71)	(3.72)	(8.59)
Fruits and Vegetables	-4.22	2.87	0.70	-1.91	1.79
	(3.37)	(4.60)	(1.76)	(1.77)	(4.08)
Tobacco	-4.13	3.74	0.39	-1.58	1.11
	(4.16)	(5.69)	(2.18)	(2.19)	(5.05)
Human Capital	7.15**	-10.46**	0.29	-0.96	-1.04
	(3.46)	(4.74)	(1.81)	(1.82)	(4.20)
Multiple Adult Households					
Log of Composite Prices					
Grain	4.30***	-0.18	-0.81*	0.73	-3.84***
	-0.84	-1.14	-0.45	-0.56	-1.16
Protein and High Calorie	-3.78***	9.34***	-0.77	0.32	-2.01
	-1.34	-1.81	-0.71	-0.89	-1.84
Fruits and Vegetables	-0.27	0.11	0.17	-0.45	1.78**
	-0.65	-0.88	-0.34	-0.43	-0.89
Tobacco	0.46	-0.22	0.27	-0.53	1.51
	-0.93	-1.26	-0.49	-0.61	-1.28
Human Capital	1.66**	-1.94**	0.45	0.97**	-2.70***
	-0.69	-0.92	-0.36	-0.45	-0.94
Additional Controls:					
Spline Per Capita Exp.	Yes	Yes	Yes	Yes	Yes
Urban/Rural Residence	Yes	Yes	Yes	Yes	Yes
Household Composition	Yes	Yes	Yes	Yes	Yes
Wave Fixed Effects	Yes	Yes	Yes	Yes	Yes
Household Fixed Effects	Yes	Yes	Yes	Yes	Yes

Table 2.5:

Demand System (6 Goods) Estimates

	Grain	Protein and High Calorie	Fruits and Vegetables	Tobacco	Human Capital
Single Adult Households					
Log of Composite Prices					
Grain	2.71	4.67	2.11	2.68	-11.68**
	(4.52)	(6.18)	(2.36)	(2.37)	(5.48)
Protein and High Calorie	-15.00**	1.32	7.66**	13.53***	-5.08
	(7.08)	(9.69)	(3.71)	(3.72)	(8.59)
Fruits and Vegetables	-4.22	2.87	0.70	-1.91	1.79
	(3.37)	(4.60)	(1.76)	(1.77)	(4.08)
Tobacco	-4.13	3.74	0.39	-1.58	1.11
	(4.16)	(5.69)	(2.18)	(2.19)	(5.05)
Human Capital	7.15**	-10.46**	0.29	-0.96	-1.04
	(3.46)	(4.74)	(1.81)	(1.82)	(4.20)
2 Adult Households					
Log of Composite Prices					
Grain	4.71***	-0.59	0.29	0.42	-5.10***
	(1.28)	(1.81)	(0.69)	(0.81)	(1.77)
Protein and High Calorie	-4.07**	12.53***	-0.18	0.57	-4.67*
	(2.05)	(2.89)	(1.11)	(1.29)	(2.82)
Fruits and Vegetables	0.70	0.45	0.42	-0.59	1.96
	(0.99)	(1.40)	(0.53)	(0.62)	(1.37)
Tobacco	1.80	-1.52	0.66	-1.09	2.71
	(1.43)	(2.02)	(0.77)	(0.90)	(1.97)
Human Capital	2.69**	-1.28	0.21	0.08	-3.95***
	(1.05)	(1.48)	(0.57)	(0.66)	(1.44)
3+ Adult Households					
Log of Composite Prices					
Grain	3.99***	0.41	-1.62***	0.82	-2.97**
	(1.12)	(1.45)	(0.58)	(0.76)	(1.51)
Protein and High Calorie	-3.83**	7.04***	-0.99	0.09	-1.15
	(1.78)	(2.31)	(0.93)	(1.21)	(2.40)
Fruits and Vegetables	-0.93	0.00	0.00	-0.34	1.81
	(0.86)	(1.12)	(0.45)	(0.59)	(1.16)
Tobacco	-0.55	0.76	0.03	-0.19	0.27
	(1.23)	(1.59)	(0.64)	(0.83)	(1.65)
Human Capital	0.84	-2.45**	0.65	1.74***	-2.02*
	(0.91)	(1.17)	(0.47)	(0.62)	(1.22)
Additional Controls:					
Spline Per Capita Exp.	Yes	Yes	Yes	Yes	Yes
Urban/Rural Residence	Yes	Yes	Yes	Yes	Yes
Household Composition	Yes	Yes	Yes	Yes	Yes
Wave Fixed Effects	Yes	Yes	Yes	Yes	Yes
Household Fixed Effects	Yes	Yes	Yes	Yes	Yes

Table 2.6:

Tests of the Unitary and Collective Rationality Models: 6 Good Demand System with Household Fixed Effects

	Single Adult	Multiple Adults
Tests of Symmetry:		
Wald Statistic from Joint Test	9.90	545.71
P-Value	0.45	0.00
Tests of Collective Rationality:		
Browning and Chiappori Linear Test		
Rank less than or equal to 2		
Wald Statistic	0.83	27.97
P-Value	0.84	0.00
Borderline Singular Value Test		
Rank less than or equal to 2		
P-Value	0.18	0.01
Rank less than or equal to 4		
P-Value	0.86	0.49
Asymptotic Distribution of Singular Values Test		
Rank less than or equal to 2		
Wald Statistic	1.39	83.07
P-Value	0.99	0.00

Table 2.7:

Tests of the Unitary and Collective Rationality Models: 6 Good Demand System No Fixed Effects

	Single Adult	Multiple Adults
Tests of Symmetry:		
Wald Statistic from Joint Test	3.47	175.09
P-Value	0.99	0.00
Tests of Collective Rationality:		
Browning and Chiappori Linear Test		
Rank less than or equal to 2		
Wald Statistic	9.60	8.45
P-Value	0.14	0.20
Borderline Singular Value Test		
Rank less than or equal to 2		
P-Value	0.21	0.69
Rank less than or equal to 4		
P-Value	0.95	0.67
Asymptotic Distribution of Singular Values Test		
Rank less than or equal to 2		
Wald Statistic	22.06	29.59
P-Value	0.04	0.02

Table 2.8:

Tests of the Unitary and Collective Rationality Models:
6 Good Demand System with Household Fixed Effects

	Single Adult	2 Adults	3+ Adults
Tests of Symmetry:			
Wald Statistic from Joint Test	8.26	98.99	413.19
P-Value	0.60	0.00	0.00
Tests of Collective Rationality:			
Browning and Chiappori Linear Test			
Rank less than or equal to 2			
Wald Statistic	0.10	17.12	21.78
P-Value	0.99	0.00	0.00
Borderline Singular Value Test			
Rank less than or equal to 2			
P-Value	0.70	0.62	0.03
Rank less than or equal to 4			
P-Value	0.82	0.77	0.61
Asymptotic Distribution of Singular Values Test			
Rank less than or equal to 2			
Wald Statistic	0.21	34.71	60.15
P-Value	0.99	0.00	0.00

Table 2.9:

Tests of the Unitary and Collective Rationality Models: 6 Good Demand System No Fixed Effects

	Single Adult	2 Adults	3+ Adults
Tests of Symmetry:			
Wald Statistic from Joint Test	2.99	81.15	105.19
P-Value	0.99	0.00	0.00
Tests of Collective Rationality:			
Browning and Chiappori Linear Test			
Rank less than or equal to 2			
Wald Statistic	9.60	4.08	6.52
P-Value	0.12	0.68	0.37
Borderline Singular Value Test			
Rank less than or equal to 2			
P-Value	0.65	0.73	0.15
Rank less than or equal to 4			
P-Value	0.67	0.60	0.70
Asymptotic Distribution of Singular Values Test			
Rank less than or equal to 2			
Wald Statistic	21.68	22.24	16.45
P-Value	0.16	0.14	0.42

3

Are Rural Markets Complete? Prices, Profits, and Recursion

3.1 Introduction

The agricultural household model has played a central role in both empirical and theoretical studies in economics. The baseline model incorporates a production process into the standard utility maximization framework, and has been used in a wide array of applications from the study of nutritional decisions, (Strauss, 1982, 1984), intrahousehold efficiency, (Udry, 1996), agricultural productivity shocks, (Jayachandran, 2006), property rights, (Field, 2007), and child labor, (Akresh and Edmonds, 2011), among many others. This chapter defines and executes a test of the agricultural household model utilizing data from the Work and Iron Status Evaluation of Central Java, Indonesia, similar to chapter 2.

Under the baseline assumption of complete markets in the neoclassical model, the simultaneous production and utility maximization problem may be modeled recursively with farm profit maximization occuring in a first stage independent of household characteristics. Families then utilize the profit from their farm business as a source of income in a second stage utility maximization process (Singh et al., 1986). The separation of the joint problem is an incredibly useful result for both theoretical and empirical applications, as it allows one to analyze production decisions independently of preferences and household characteristics.

However, the necessary condition of complete markets is a strong assumption that warrants empirical investigation. To assess the validity of the recursive framework, a number of previous studies have tested if production may be treated independently from household characteristics (Pitt and Rosenzweig, 1984; Benjamin, 1992; Jacoby, 1993; Bowlus and Sicular, 2003; LaFave and Thomas, 2012). These tests rely on specifying a production process for the household, and often require restrictive assumptions regarding the form of the underlying process. Results of these tests are mixed, with seminal works failing to reject the implications of complete markets providing the basis for studies which exploit the advantages of the two-step, recursive structure (Pitt and Rosenzweig, 1984; Benjamin, 1992).

Recent evidence on the non-substitutability of family versus hired labor in agricultural production suggests that a test of complete markets abstracting from the functional form of the production process would offer considerable advantages (LaFave and Thomas, 2012). This paper defines and executes such a test based on the consumption allocations of households that is free of potentially confounding assumptions regarding farm production. By exploiting the timing of the two stage model where consumption allocations are made after profit maximization, we provide new empirical evidence to reject the implications of recursion in the agricultural household model.

In order to test the predictions of complete markets on consumption allocations, we estimate a household demand system drawing on rich longitudinal consumption and price data from the Work and Iron Status Evaluation (WISE) in Purworejo, Indonesia. Along with a randomized iron supplement intervention, WISE collected detailed longitudinal data on participating individuals, households, and the communities in which they live. Of particular importance, the data includes transaction prices elicited monthly from local markets, shops, and stalls within each of the 146 WISE communities over a five-year period. The combination of household panel data with market prices offers the unique combination of information on expenditures, consumption prices, and farm input prices that make the complementary test of complete markets possible.

The results of this new test reject the implications of separation, and suggest that household behavior is inconsistent with a world of complete markets. These findings are inconsistent with seminal work in the literature using data from Indonesia, but complement more recent evidence from the production side using WISE data (LaFave and Thomas, 2012). We further show that the rejections of complete markets are concentrated in households at the bottom of the socioeconomic status distribution, while those at the top are able to operate as if complete markets exist.

The next section presents a dynamic version of the neoclassical agricultural household model appropriate for our longitudinal data and focuses on the implications of complete markets for consumption allocations. The empirical demand system is outlined in Section 3.3, and the unique survey and price data is discussed in Section 3.4. Section 3.5 presents the results rejecting complete markets, and Section 3.6 concludes with a discussion of the implications of our findings.

3.2 Recursive Agricultural Household Model

This section presents a dynamic agricultural household model with a focus on the implications of complete markets for consumption allocations. As will be clear, these testable implications are free of a number of concerns regarding the specification of the production process relied upon by alternative testing strategies.

Farm households face the objective of maximizing discounted expected future utility subject to a production process, endowment of time, and intertemporal budget constraint. Formally, households choose consumption goods, farm inputs, and leisure to:

$$\max\ E\left[\sum_{t=0}^{\infty}\beta^t u(x_{mt}, x_{at}, \ell_t; \mu_t, \varepsilon_t)\right] \tag{3.1}$$

subject to:

$$Q_t = Q_t(L_t, V_t, A_t) \tag{3.2}$$

$$E^L = \ell_t + L_t^F + L_t^O \tag{3.3}$$

$$W_{t+1} = (1+r_{t+1})\left[W_t + w_t(E^L - \ell_t) + p_{at}Q_t(t) - w_t L_t - p_{vt}V_t - p_{At}A_t - p_{mt}x_{mt} - p_{at}x_{at}\right] \tag{3.4}$$

where x_{mt} is a vector of market consumption goods, x_{at} is consumption of agricultural goods (i.e. food, some of which may be grown by the household), and ℓ_t is a vector of household members' leisure. Preferences are captured by μ_t and ε_t, which include observed and unobserved characteristics that parameterize the utility function such as household size and composition. The agricultural production function relates labor, L_t, variable inputs such as seed and fertilizer, V_t, and farm land, A_t, to output.[1,2] Household members may work on the family farm, L_t^F, or off, L_t^O, as

[1] In the rural Indonesian setting of the Work and Iron Status Evaluation, family farms remain generally stable over time.

[2] Capital is not explicitly included in the production function, as farms in the region have small capital stocks, and what capital does exist, such as sickles to harvest rice, can effectively be thought of as variable inputs. Including a capital in the output function and specifying a law of motion for capital over time does not change the empirical predictions tested in this chapter.

is done by approximately two-thirds of household members. The budget constraint defines how wealth, W_t, transitions between periods earning interest at rate r_{t+1}.

As has been shown in the literature, the solution to this joint production-consumption problem when all current and future markets exist and prices are taken as given reveals that the optimal choice of farm inputs is determined as if households operate their farms as stand-alone profit maximizing firms independent of their households (Singh et al., 1986; Benjamin, 1992). The separation between production and household characteristics implies the joint problem may be formulated recursively as a two-step process.[3]

3.2.1 Two-Step Approach

Profit Maximization

In the first stage, households maximize profits on their farms as if they are operating independent businesses. Farmers choose farm labor, variable inputs, and land to maximize farm profits. Letting π_t represent farm profits, households solve the following problem in the first stage:

$$\max \pi_t = p_{at} Q_t(L_t, V_t, A_t) - w_t L_t - p_{vt} V_t - p_{At} A_t \tag{3.5}$$

Note that this same profit maximization problem is nested in the joint problem, as the expression for farm profits directly appears in the intertemporal budget constraint in equation (3.4).

Solving this problem results in input demand functions that depend on wages, output prices, and input prices. Optimal choices of farm inputs are determined according to straightforward first order conditions that relate the prices of the inputs to their marginal product. The results of this first stage can be summarized by the following profit function, which is independent of household characteristics or preferences:

[3] Strauss and Thomas (1986) illustrates the recursive form of the model and derives the bordered Hessian matrix for the static version of the farm households problem under complete markets. The block diagonal form of the bordered Hessian illustrates how production decisions may be modeled as independent of consumption side variables.

$$\pi_t^* = \pi_t^*(p_{vt}, p_{at}, w_t, p_{At}) \tag{3.6}$$

Utility Maximization

Once optimal production decisions have been made, households take the profits from the farm business as given in the second stage utility maximization process; farmers effectively return to their households with a lump sum of resources to use in maximizing household utility. The budget constraint limiting the utility maximization process in the second stage is now a modified version of equation (3.4). Where profit maximization was imbedded in the previous budget constraint, π^* now takes the place of the production choices:

$$W_{t+1} = (1 + r_{t+1}) \left[W_t + w_t(E^L - \ell_t) - p_{mt}x_{mt} - p_{at}x_{at} + \pi_t^*(p_{vt}, p_{at}, w_t, p_{At}) \right] \tag{3.7}$$

Equation (3.7) exhibits the basis for the complementary test of separation. Under the assumption of complete markets, the farm business influences utility maximization and consumption allocations only by shifting the budget constraint by π^*, the amount of income provided by farm profits.

Having made optimal production choices, the result of the second stage utility maximization problem is a set of conditional demand functions. These follow a similar form to those obtained in standard intertemporal models, and depend on prices, income, and the marginal utility of wealth. However, the inclusion of the production component in the agricultural household model and recursion under complete markets results in the functions being augmented by farm profits in a particular way. The demand for consumption good c in period t is the following:

$$x_{ct} = x_{ct}(p_{mt}, p_{at}, w_t, r_{t+1}, \pi_t^*(p_{vt}, p_{at}, w_t, p_{At}), y_t, \lambda_t; \mu_t, \varepsilon_t) \tag{3.8}$$

where consumption depends on market and agricultural prices, p_{mt} and p_{at}, wages, interest rates, farm profits, π_t^*, income, y_t, and expected future prices through the marginal utility of wealth, λ_t. The key feature of the recursive framework is visible in equation (3.8). When recursion holds, the family farm only affects consumption demands through the profits determined in the first stage. As a result, changes in variables that only appear in the profit function will impact consumption allocations in a similar way. In particular, the prices of variable inputs, p_{vt}, are weakly separable from consumption demand. A change in the price of a farm input such as fertilizer or insecticide, impacts demand only through its effect on profits.

This prediction of the model leads to a testable implication of complete markets that assesses whether farm input prices are weakly separable for consumption demand.

3.2.2 Recursion and Consumption Allocations

Previous work in the literature has focused exclusively on the predictions of complete markets for the first stage of the recursive formulation of the agricultural household model (LaFave and Thomas, 2012). As stated in the introduction, in order to execute these tests, additional restrictive assumptions are made regarding the functional form of the production function and labor inputs.[4]

However, recent evidence suggests that the homogeneity of labor, either explicitly or implicitly assumed by past work, may not be an accurate representation of rural labor markets (LaFave and Thomas, 2012). One distinct advantage of the test of complete markets in the second stage of the recursive model is the ability to abstract from a number of these concerns.

A close examination of equation (3.8) shows that the separation between consumption and production imposes a restriction on how factors that only impact profits go on to impact demand. When recursion holds, the prices of variable farm inputs, factors of production that are used only in farm production but not consumed on their own, impact consumption solely through profits.[5] This weak separability restriction provides a test of recursion under complete markets similar to the ratio

[4] The seminal paper in the literature specifies a Cobb-Douglas production function and a single homogeneous type of labor Benjamin (1992). A number of works following this early work continue with this specification.

[5] Note that this is not true of all prices from the production side. Wages and the price of agricultural output, w_t and p_{at}, directly enter consumption demands.

test utilized in LaFave and Thomas (2012).

The test is derived by considering the marginal effect of a change in a input price, p_{vt}, on the demand for good c. Based on the form of (3.8), this derivative can be decomposed into two parts; the effect of a change in the input price on profits, and the impact of a change in profits on consumption:

$$\frac{\partial x_{ct}}{\partial p_{vt}} = \frac{\partial x_{ct}}{\partial \pi_t^*} \frac{\partial \pi_t^*}{\partial p_{vt}} \tag{3.9}$$

The proposed test exploits this recursive property under the null of complete markets. Suppressing t subscripts for simplicity, consider the marginal effect of a change in two different input prices f and i, fertilizer and insecticide for example, on good c:

$$\frac{\partial x_c}{\partial p_f} = \frac{\partial x_c}{\partial \pi^*} \frac{\partial \pi^*}{\partial p_f} \tag{3.10}$$

$$\frac{\partial x_c}{\partial p_i} = \frac{\partial x_c}{\partial \pi^*} \frac{\partial \pi^*}{\partial p_i} \tag{3.11}$$

In both derivatives, the first term is independent of the input price, and the second component is independent of the consumption good c. As a result, the ratio of the two derivatives will be independent of good c:

$$\frac{\frac{\partial x_c}{\partial p_f}}{\frac{\partial x_c}{\partial p_i}} = \frac{\frac{\partial x_c}{\partial \pi^*} \frac{\partial \pi^*}{\partial p_f}}{\frac{\partial x_c}{\partial \pi^*} \frac{\partial \pi^*}{\partial p_i}} = \frac{\frac{\partial \pi^*}{\partial p_f}}{\frac{\partial \pi^*}{\partial p_i}} \tag{3.12}$$

This relationship provides the basis for a test of separation that abstracts away from the function form of the production process. Any variable that is a part of the second-stage utility maximization problem only through π^* must impact all demands in a similar way through profits. Empirically, when recursion holds, the ratio of marginal effects of input prices should be the same for all consumption goods.

In order to test this restriction, we estimate a flexible demand system and examine the ratio of price effects on consumption allocations. Testing this restriction of separation requires detailed data not only on consumption goods but also agricultural input prices. We move next to defining the empirical strategy.

3.3 Household Demand Systems and Empirical Implementation

This section presents an empirical specification for a household demand system based on the Working-Leser model that we use to test the ratio restrictions implied by recursion. Budget shares of aggregated food and non-food goods are regressed against composite consumption prices, variable input prices, and a flexible function of per capita expenditure (PCE).

While Working-Leser curves are well grounded in theory, a limitation of the model is its imposition of a linear form for the relationship between the log of per capita expenditure and the budget share for each good. This functional form has the disadvantage of being prone to influential observations in the extreme values of PCE, and forces a linear relationship where it may not be appropriate.[6] To address this concern, a piece-wise linear function of PCE is used to allow the demand functions to have a more flexible shape and limit the influence of extreme values.

Let the share of expenditure, w, on composite good c for household h in locality j and wave t be the following:

$$w^c_{hjt} = \alpha + \sum_{c=1}^{C} \beta_c log(p^c_{jt}) + \sum_{v=1}^{V} \gamma_v log(p^v_{jt}) + f(x_{hjt}; \delta) + \theta z_{hjt} + \mu_h + \varepsilon_{hjt} \qquad (3.13)$$

This conditional demand function includes the log of each composite consumption prices, p^c_{jt}, as well as the log price of variable farm input prices, p^v_{jt}, such as seeds, fertilizer and insecticide. Household per-capita expenditure, x_{hjt}, enters through the flexible function $f(\cdot)$ that is parameterized by δ. Here $f(\cdot)$ is specified as a spline with three knot points to allow expenditure to impact demand in a flexible way. Additional time varying household controls are included in z_{hjt} including household

[6] This issue is true for other parametric demand specifications including the Almost Ideal Demand System (Deaton, 1988), and Quadratic Almost Ideal Demand System (Banks et al., 1997).

composition and size, age and education of the household head and spouse, and wave, year, and season indicators.

The empirical analysis in this chapter draws from the same Work and Iron Status Evaluation panel data utilized in chapter 2 of this dissertation. The panel structure of the WISE data allows one to include a household fixed effect, μ_h, to capture all additive and time invariant observed and unobserved heterogeneity. The analysis looks within households over time without the concern that stable unobserved factors at the household or farm level are biasing the results. These factors, such as unobserved farm characteristics like soil quality or farm-specific knowledge, may be related to input choices, are could potentially bias estimates of the input prices in the demand system.

Recall from equation (3.8) that when recursion holds, the ratio of the marginal price effects of any two input prices will be the same regardless of which consumption good one considers. In terms of equation (3.13), the ratio of two elements of γ should be the same regardless of the consumption share on the left-hand side. For clarity, consider two goods, food and utilities, and two input prices, fertilizer and insecticide. Under the null of recursion, the following must hold:

$$\frac{\gamma_{fert}^{food}}{\gamma_{insect}^{food}} = \frac{\gamma_{fert}^{util}}{\gamma_{insect}^{util}} \tag{3.14}$$

This same relationship must hold for each combination of consumption goods and prices. More generally, for composite goods c and d, and input prices f and i, the null hypothesis under complete markets is:

$$H_0 : \frac{\gamma_f^c}{\gamma_i^c} = \frac{\gamma_f^d}{\gamma_i^d} \quad \forall\ c, d, f, i \tag{3.15}$$

Alternatively:

$$H_0 : \gamma_f^c \gamma_i^d = \gamma_i^c \gamma_f^d \quad \forall\ c, d, i, f \tag{3.16}$$

It is important to note that the equivalence of ratios must hold not only jointly across all consumption goods and input prices, but for each combination as well. These cross equation restrictions are tested using a non-linear Wald test allowing for clustering at the household level.

3.4 Data

While a clear theoretical prediction, the data required to implement tests of recursion on the consumption side are extensive and difficult to collect. Few surveys contain detailed data on consumption behavior, market consumption prices, as well as agricultural input prices. Even fewer have the data recorded frequently over a multi-year time horizon. We utilize new data from the Work and Iron Status Evaluation (WISE) in Purworejo, Indonesia to implement the tests defined in the previous section (Thomas et al., 2011).

Alongside a randomized iron supplement intervention, WISE collected a large-scale longitudinal survey containing detailed information on individuals, households, and the communities in which they live. A major component of the project that makes this paper possible was the collection of transaction price data at the community level from direct visits to local markets, shops, and stalls.

The panel nature of the WISE data allows us to utilizes household fixed effects to sweep away time invariant heterogeneity, and identify the price effects from changes within households over time. In order for such an exercise to be valid, maintaining minimal attrition is essential. Participant households were interviewed every four months beginning in 2002 and continuing through 2005, with a longer-term follow-up conducted five years from the start of the survey in 2007. As a testament to the research teams effort to track respondents over all waves of the survey, ninety-seven percent of the original farm households from the 2002 baseline were interviewed five years later in the 2007 wave.[7]

[7] Thomas et al. (2011) reports further on attrition and the tracking scheme used in the WISE study.

3.4.1 Household Expenditure Data

Household expenditure is measured through a module given to the household head recording information on goods purchased or produced at home for consumption. The survey contains 14 food groups and 11 non-food groups. For the body of the results, these goods are aggregated to estimate a four good demand system including staple grains, other food, expenditure on home goods such as utilities, rent, and household items, and human capital expenditures including education and health. Aggregating consumption to this level aids in precisely estimating the price effects which is essential for the ratio tests. Results using an expanded demand system with other food further disaggregated are consistent with those presented in the next section and appear in the appendix tables for this chapter (tables A.13, A.14, and A.15). Table A.11 in the appendix for this chapter summarizes the aggregation of the composite consumption goods.

3.4.2 Community Price Data

Assessing the predictions of the model relies on precisely estimating the impact of both consumption and variable input prices on consumption demands. Accurately measuring the prices households face in the marketplace is an extremely difficult task, and one not often undertaken by household surveys. This chapter benefits from the efforts of the survey team to explicitly measure prices in each WISE community. In many household studies, the only available measure of prices are from unit-values, the amount of expenditure on a group of goods divided by the quantity purchased. However, a major concern with this approach is that unit-values conflate both price and quality variation, and do not reflect the prices households face in the market.

A common approach in the demand estimation literature when prices are unobserved is to adopt a method developed in Deaton (1988) to estimate both price and quality effects. In order to do so, one must be willing to assume weak separability amongst the defined consumption groups, and that demand functions are loglinear. These are not innocuous assumptions. As discussed in McKelvey (2011), using unit-values may still cloud the analysis with unmeasured quality variation and systematic measurement error. McKelvey rejects the assumptions required of the Deaton method in the same WISE data used in analysis presented below, highlighting the importance of the transaction price data.

Within each community, WISE enumerators solicited prices from street stalls, shops, markets, and community informants for a large series of commonly purchased goods. In addition, surveyors visited multiple farm stores in each community to obtain information on the prices of agricultural inputs such as seeds, fertilizers, and insecticides. This is an incredible benefit of the WISE survey, as the simultaneous collection of consumption prices, agricultural input prices, and expenditure data presents a unique opportunity to test the implications of recursion on consumption behavior.

Great care was taken by the survey team to ensure that prices were collected for the same quality, brand, and size of each good in the price surveys. In the few cases that a particular size and brand was not available, the price of a pre-specified close substitute good was recorded along with its brand, size, and additional identifying information. This process results in price data with both low quality variation and few missing values. Enumerators followed the same procedure to collect transaction prices for farm inputs, including seeds, fertilizers, and insecticides. The price surveys occurred alongside data collection at the household level, resulting in a set of prices with both spatial and temporal variation.

Prices are matched to households by computing community-date medians across sources of price information, and converted to real values using the regional price index available from Statistics Indonesia, Badan Pusat Statistik (BPS). The date a household was interviewed within a wave and in which community it resides determines the set of prices it receives. The consumption prices are then used to create composite prices to match the aggregated consumption goods in the demand system. The weight each price receives is determined by the share of expenditure on the good in the 2002 SUSENAS expenditure survey for households in Purworejo.[8] Table A.2

[8] The 2002 SUSENAS was given during the same time period as the baseline of WISE, and contains a long-form expenditure module to facilitate calculating the weights for the composite prices.

of the appendix summarizes the aggregation of the composite prices corresponding to the demand system goods, whether data from markets (pasars) or stores (tokos) are used, and the weight it receives in the aggregation.[9] The agricultural input prices are normalized using the same regional price index, but are not aggregated in any way.

Table 3.1 reports means and standard errors of household expenditure, demographics, and community prices. Due to the agricultural price surveys beginning in December of 2003 after WISE had already begun, the estimation sample in this chapter uses 8 of the 11 waves used in the previous chapter. The sample is also limited to those households living within WISE communities, as the price surveys were only administered in the communities selected for the WISE study. As the analysis focuses on agricultural households, this poses less of a concern than it may otherwise, as family farms tend to be stable over the four-year period of the data. The estimation sample consists of approximately 3,800 unique farm households and 29,000 household-wave observations.

Households spend approximately 60% of their budget on food, and the remaining 40% on non-food items, with per capita expenditure averaging 200,000Rp per person per month (approximately 20USD). Prices of composite and input goods are recorded in Rp0,000 (approximately 1USD) and appear in column 2. Four input prices are used: the price of IR64 rice seed, a common high-yield variety rice, kangkung seed, a leafy green vegetable similar to spinach, and common varieties of fertilizer and insecticide. The prices of fertilizer and insecticide are particularly valuable as they should not have any substitution effects that seed prices may have. These input goods are frequently purchased, and should impact consumption demands only through a profit effect if markets are complete.

A key condition in the empirical analysis is that the input prices are not related to the composite consumption prices. If the price of rice seed is strongly correlated with the purchase price of rice, for example, this would violate the test relying on the input

[9] The distinction of markets or stores for the source of price information is determined based on the frequency of purchase and stock of each source.

price only impacting demand through a profit effect. This is an empirical question, and one addressable in the data. There seems to be no evidence of such a connection between seed and market purchase prices. A regression of the log market price of rice on the log price of rice seed while controlling for locality and time effects returns a coefficient of 0.003 with a standard error of 0.039 on rice seed prices, suggesting seed and output prices are unrelated.[10]

The next section presents results from estimating the composite demand system and tests of recursion.

3.5 Results

3.5.1 Demand System Estimates

Table 3.2 reports estimates of the price and income effects from equation (3.13) where budget shares are measured 0 to 100. Standard errors appearing below the point estimates are clustered at the household level.

Before presenting tests of the model, it is informative to examine the price and income effects from the modified Working-Leser Engel curves. As is expected, the uncompensated own-price elasticity estimates, the coefficients on the composite price for its corresponding good, are negative and precisely estimated for home and human capital goods. In contrast, the own-price elasticity for grain is positive and statistically significant, implying that a one percent increase in the composite price of grain is related to a two percent increase in the share of expenditure spent on staple grains. The agricultural household model provides a theoretical justification for this result as an increase in the price of the farm's output good includes a profit effect that is absent from standard demand systems.[11] It is possible that the positive own-price elasticity of grain is the result of the increase in farm revenue when the price of rice increases.

[10] These estimates are from the following regression: $\log(p_{jt}^{rice}) = \alpha + \beta \log(p_{jt}^{riceseed}) + \mu_t + \mu_j + \varepsilon_{jt}$, where j indexes communities and t waves.

[11] This is clear in the model in Section 3.2 and equation (3.8). The price of agricultural goods, p_{at}, influences consumption demand through farm profits in the conditional demand function in equation (3.8).

The estimated γ coefficients on the farm input prices are jointly significant for each composite good. The precision of these estimates is essential in testing the equivalence of their ratios across equations. While these input prices are allowed to affect consumption goods, they must do so in a way that reflects the separation between production and consumption in order to be consistent with complete markets.

3.5.2 Separation Tests

Tests of recursion rely on assessing whether the ratios of the coefficients of the input prices in table 3.2 are equivalent. These ratios are calculated using the delta method and reported in table 3.3, with standard errors again allowing for arbitrary correlation within a household. Each ratio reflects a combination of coefficients. For example, -0.85 in column 1 of table 3.3, is the ratio of the coefficient on kangkung seed to rice seed in the grain demand function (the ratio of 0.73 to -0.62 from table 3.2). The ratios are generally small, although a number are imprecisely estimated and statistically indistinguishable from zero. This imprecision may lead toward failing to reject complete markets, as ratios that are imprecisely estimated will be indistinguishable from each other in the cross-equation, nonlinear Wald test even if the point estimates are quite different. As the Wald test is notoriously weak, rejections of the equivalence of these ratios should therefore be seen as clear violations of recursion.

The results of the ratio tests of complete markets appear in table 3.4. The table reports the p-values for the non-linear Wald tests of the cross equation ratio restrictions defined by equation (3.15). Each cell represents the p-value for the pairwise test between the two prices listed in the column and the two goods listed in the row. For example, the value of 0.375 in column 1 is the p-value for the test that the ratio of the price coefficients for rice seed and kangkung seed are the same when estimating demand for grains and other food. From table 3.3 these ratios are -0.85 and -0.37. Values above a critical value suggest that we fail to reject the null that recursion holds.

In contrast, the value of 0.013 in column 3 rejects that the ratios for rice seed to fertilizer are the same across grain and other food demand functions (whether 3.11 is equal to -0.22). This test and others that reject the predictions of complete markets at the 10% level or below are highlighted in bold.

In the aggregated demand system estimated in this chapter, there are 36 pair-wise restrictions to test as well as the overarching tests of equality of all 24 ratios in table 3.3. The results of these tests provide clear evidence to reject recursion and complete markets. Of the 36 pair-wise tests, 11 reject the equality imposed by recursion at the 5% level, and 15 at the 10% level. In order for the demand system to be consistent with complete markets, *all* of the p-values must be above a reasonable range of rejection, a condition that is clearly violated.

With 36 tests, one could certainly expect to statistically detect a small number of false rejections purely out of chance. However, with nearly one-third of the tests rejected at the 5% level, the results are in clear violation of recursion.[12] These results reject standard assumptions in the literature but confirm more recent results presented in LaFave and Thomas (2012). In contrast to seminal work in the literature, household behavior in rural Indonesia appears inconsistent with the predictions of complete markets.

3.5.3 Are Markets Complete for a Select Few?

Prior work often acknowledges that while the average effect may show that households are unable to smooth consumption or operate as if markets are complete, market sophistication may be a valid characterization for a subset of the population (Townsend, 1994; LaFave and Thomas, 2012). This section provides evidence of such heterogeneity by showing that rejections of complete markets are concentrated amongst households at the bottom of the socioeconomic status distribution.

Table 3.5 reports results of the ratio tests mirroring those in table 3.4, but for stratified samples. Households are divided into those who own more than the within community mean of land ownership versus those who own less than the within com-

[12] These results are corroborated by the disaggregated demand system presented in the appendix tables for this chapter, tables A.13, A.14 and A.15.

munity mean of land holdings. Panel A summarizes the key findings: after dividing the sample, the rejections of complete markets are concentrated amongst the small landowners. Out of the 36 pairwise tests for each group, 14 are rejected at the 10% level for those households at the bottom of the distribution while only 1 is rejected for those households at the top.

This result provides support for our findings and the ability of our test to provide rejections of market completeness. Consistent with past work, the results suggest that those households at the top of the socioeconomic status distribution are able to function as if markets are complete.

3.6 Conclusion

This chapter provides evidence on the inconsistencies of complete markets in rural Indonesia from a new test of complete markets. By exploiting that consumption allocations are made after profit maximization in the recursive form of the agricultural household model, we are able to test the implications of separation without relying on restrictive assumptions of the production process.

Using new, longitudinal consumption and transaction price data from the Work and Iron Status Evaluation, the results show a link exists between agricultural production and consumption allocations that is inconsistent with complete markets. These results are inconsistent with seminal papers upholding the recursive model (Pitt and Rosenzweig, 1984; Benjamin, 1992), and offer support to more recent evidence on the complexities of rural markets.

Future work will look to push forward on determining the underlying causes of the failures of complete markets. The question of separation and complete markets is not only important as a technical matter, but for what it reveals about the market environment in developing settings. Recognizing market complexities is essential in designing and evaluating development policy around the world.

3.7 Tables

Table 3.1:

Descriptive Statistics

Household Characteristics	(1) **Mean (se)**	*Community Prices* (Rp0,000)	(2) **Mean (se)**
Share of Expenditure on [...]		*Price of [...]*	
Grain	16.67	Grain	0.22
	(0.05)		(0.0001)
Other Food	43.69	Other Food	0.70
	(0.07)		(0.0002)
Home Goods	19.64	Home Goods	1.79
	(0.05)		(0.001)
Human Capital	20.00	Human Capital	0.23
	(0.08)		(0.0001)
Per Capita Expenditure	203.71	*Input Prices*	
(Rp000/mo)	(0.95)	Rice seed	1.51
Years of Education of [...]			(0.001)
Primary Male	5.59		
	(0.02)	Kangkung Seed	1.99
Primary Female	5.09	(water spinach)	(0.002)
	(0.02)		
Age of [...]		Insecticide	3.94
Primary Male	54.54		(0.003)
	(0.08)		
Primary Female	49.41	Fertilizer	5.25
	(0.07)		(0.003)
Household Size	3.76		
	(0.01)		
Urban (%)	13.42		
	(0.20)		
Wet Season (%)	47.49	N. Waves	8
	(0.29)	N. Households	3825
		N. Observations	29101

Notes: Table reports means and standard errors for variables of interest over the first waves of WISE used in the demand system estimation. Column 1 reports household level characteristics and column 2 community level prices. The sample consists of households with farm businesses, approximately 75% of households in the survey. Per capita expenditure is in real Rp000/mo and all prices in real Rp0,000 with January 2002 as the base (approximately 1USD). See appendix tables 1 and 2 for detailed information on the consumption goods used in creation of the composite expenditure shares and prices.

Table 3.2:

Demand System Estimates

	Share of Household Expenditure on [...]			
	(1)	(2)	(3)	(4)
	Grain	**Other Food**	**Home Goods**	**Human Capital**
log of Composite Prices				
Grain	2.14**	-1.00	-0.44	-0.70
	(0.92)	(1.30)	(0.68)	(1.24)
Other Food	-0.20	2.00	0.41	-2.21
	(1.66)	(2.47)	(1.32)	(2.30)
Home Goods	-1.30	2.64**	-0.45	-0.88
	(0.82)	(1.22)	(0.64)	(1.19)
Human Capital	1.97**	0.36	1.21*	-3.54***
	(0.87)	(1.21)	(0.62)	(1.15)
log of Farm Input Prices				
Rice Seed	0.73	-4.47***	2.43***	1.31
	(0.86)	(1.24)	(0.71)	(1.15)
Kangkung Seed	-0.62**	1.64***	-0.65**	-0.37
	(0.31)	(0.45)	(0.26)	(0.44)
Insecticide	0.03	-0.97	-1.19**	2.12**
	(0.79)	(1.14)	(0.59)	(1.06)
Fertilizer	2.28***	0.99	0.34	-3.61***
	(0.72)	(1.07)	(0.56)	(1.01)
Splines in log(PCE)				
0-25th Percentile	2.27***	11.38***	-14.93***	1.28**
	(0.61)	(0.66)	(0.38)	(0.55)
25th-50th Percentile	-4.11***	11.30***	-11.51***	4.33***
	(0.67)	(0.90)	(0.44)	(0.79)
50th-75th Percentile	-3.27***	7.33***	-11.35***	7.29***
	(0.61)	(0.98)	(0.47)	(0.98)
75th-100th Percentile	-0.93***	2.03***	-8.81***	7.71***
	(0.36)	(0.78)	(0.29)	(0.92)
Household Fixed Effects	Yes	Yes	Yes	Yes
Joint Test of Input Prices				
F statistic	3.69	6.18	5.00	3.98
p-value	0.005	0.0001	0.001	0.003
Observations	29101	29101	29101	29101
N. of Households	3825	3825	3825	3825

Notes: Outcomes are shares of household expenditure on the composite good in each column, and all prices are expressed in real terms as the log of 2002 Rp0,000. Knots in the log PCE distribution are placed at the 25%, 50% and 75% percentile. Additional controls include the education and and age of the primary male and female within the household, an indicators for whether or not the household is in an urban area, household composition, and indicators for the wave, year, and season. Standard errors appear below the point estimates and are calculated allowing for clustering at the household level.

*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Table 3.3:

Price Effect Ratios

	Share of Household Expenditure on [...]			
	(1)	(2)	(3)	(4)
	Grain	**Other Food**	**Home Goods**	**Human Capital**
Coefficient Ratio of [...] to [...]				
Kangkung Seed to Rice Seed	-0.85	-0.37***	-0.27**	-0.28
	(1.02)	(0.13)	(0.13)	(0.40)
Insecticide to Rice Seed	0.04	0.22	-0.49*	1.62
	(1.07)	(0.26)	(0.29)	(1.63)
Fertilizer to Rice Seed	3.11	-0.22	0.14	-2.76
	(3.74)	(0.25)	(0.24)	(2.53)
Insecticide to Kangkung Seed	-0.05	-0.59	1.82	-5.75
	(1.27)	(0.72)	(1.12)	(7.56)
Fertilizer to Kangkung Seed	-3.67*	0.60	-0.52	9.78
	(2.12)	(0.69)	(0.86)	(12.23)
Insecticide to Fertilizer	0.01	-0.97	-3.51	-0.59**
	(0.35)	(1.28)	(5.47)	(0.29)
Observations	29101	29101	29101	29101
N. of Households	3825	3825	3825	3825

Notes: Table reports the ratios of coefficients for pairs of inputs prices from the demand system estimates in Table 2. The ratios are calculated using the delta method with standard errors allowing for clustering at the household level.
*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Table 3.4:

Separation Test Results (*p*-values)

Summary	
N. of Pairwise Ratios	36
N. of Rejections at 5%	11
N. of Rejections at 10%	15

Consumption Goods		*Ratio Test Results*						
		Rice Seed to […]			Kangkung to […]		Insecticide to	
Good A	*Good B*	Kangkung Seed	Insecticide	Fertilizer	Insecticide	Fertilizer	Fertilizer	All 6
Grain	Other Food	0.375	0.867	**0.013**	0.665	**0.007**	0.447	**0.094**
	Home Goods	0.320	0.671	**0.036**	0.316	0.136	**0.086**	0.223
	Human Capital	0.584	0.518	0.123	0.213	**0.031**	0.120	0.239
Other Food	Home Goods	0.533	**0.035**	0.210	**0.037**	0.247	0.570	0.340
	Human Capital	0.820	**0.063**	**0.005**	**0.062**	**0.004**	0.688	**0.058**
Home Goods	Human Capital	0.976	**0.043**	**0.010**	**0.070**	**0.037**	0.121	0.113
	Overall	0.316						

Notes: Table reports p-values from pairwise and joint tests of the ratio restrictions implied by separation in the agricultural household model. Each value represents the test for the pair of input prices in the column and consumption goods in the row. The final column tests equivalence across all pairs of price ratios for the goods in the corresponding row (6 restrictions). The overall joint test examines equality of all ratios reported in Table 3. Tests rejected at a 90% confidence level or above are highlighted in bold.

Table 3.5:

Separation Ratio Test Results - Sample Stratified by Household Land Holdings (p-values)

Panel A: Summary

	Household Land Holdings Relative to Community Mean: Below	Above
N. of Pairwise Ratios	36	36
N. of Rejections at 5%	7	0
N. of Rejections at 10%	14	1

Panel B: Households with land holdings below their community mean

Consumption Goods		*Ratio Test Results*						
		Rice Seed to […]			Kangkung to […]		Insecticide to	
Good A	*Good B*	Kangkung Seed	Insecticide	Fertilizer	Insecticide	Fertilizer	Fertilizer	All 6
Grain	Other Food	0.798	0.283	**0.020**	0.310	**0.018**	0.397	0.210
	Home Goods	0.932	0.894	0.107	0.859	0.175	0.229	0.589
	Human Capital	0.624	0.142	**0.096**	0.185	**0.054**	0.157	0.318
Other Food	Home Goods	0.614	**0.080**	0.644	**0.091**	0.576	0.638	0.609
	Human Capital	0.556	**0.045**	**0.028**	**0.049**	**0.018**	0.380	0.143
Home Goods	Human Capital	0.536	**0.053**	**0.045**	**0.066**	**0.093**	0.474	0.267
	Overall	0.544						

Panel C: Households with land holdings above their community mean

Good A	*Good B*	Kangkung Seed	Insecticide	Fertilizer	Insecticide	Fertilizer	Fertilizer	All 6
Grain	Other Food	0.182	0.349	0.868	0.668	0.105	0.289	0.546
	Home Goods	0.151	0.557	0.385	0.194	0.594	0.575	0.674
	Human Capital	0.671	0.490	0.546	0.647	0.165	0.189	0.687
Other Food	Home Goods	0.694	0.321	0.164	0.311	0.352	0.250	0.739
	Human Capital	0.397	0.977	0.349	0.756	**0.073**	0.767	0.584
Home Goods	Human Capital	0.499	0.590	0.133	0.889	0.292	0.258	0.679
	Overall	0.930						

Notes: Table reports p-values from pairwise and joint tests of the ratio restrictions implied by separation in the agricultural household model after stratifying the sample based on land holdings. Results for those households who own less than the within community mean appear in Panel B (n=19711). Results for those households with greater than the witin community mean appear in Panel C (n=9390). Each value represents the test for the pair of input prices in the column and consumption goods in the row. The final column tests equivalence across all pairs of price ratios for the goods in the corresponding row (6 restrictions). Demand system results for the stratified groups are available in Appendix Table A.6. Tests rejected at a 90% confidence level or above are highlighted in bold.

4

Environment and Health: The Effects of Early-Life Exposures to Environmental Contaminants in the Philippines

4.1 Introduction

Unobserved, implicit prices incentivize the behavior of market participants similar to the observed prices discussed in the previous two chapters. This study comprising the fourth and final chapter of this dissertation examines the implicit prices of environmental goods in a developing country. Economic development generally improves welfare, however economic activities that increase with development can produce detrimental changes to the environment with negative effects to health and human capital development. In particular, the negative externalities due to the undervaluation of the unobserved, implicit price of environmental quality can be observed in the effects to health and human capital in both the short and long-term. If the benefits of increasing economic activity cannot outweigh the combined short and long-term costs then it is not truly development (Meier and Rauch, 2005). This chapter aims to improve the understanding of the effects to short and long-term health and human capital of fetal and early-life exposures to multiple environmental contaminants in the developing country context of Metropolitan Cebu, Philippines. Metropolitan Cebu over the past few decades is characterized by rapid industrialization and ineffective regulation resulting in high levels of pollution. Combined with the presence of a longitudinal survey containing frequently collected detailed health information on a cohort of children beginning in 1983, Metropolitan Cebu provides an ideal context to examine the negative health effects of increasing economic activity.

Productive industrial processes employ and release to the environment tens of thousands of chemicals with hundreds introduced every year, and human consumption results in another wide variety of toxins in our surrounding environment. The vast majority of environmental toxins carry unknown effects to health and human capital.[1] As a stark example of the sheer volume of environmental toxins and the little that is known of their effects, more than 80,000 industrial substances have been registered for commercial purposes in the United States by the Environmental Protection Agency. However, the Toxic Substances and Control Act of 1976 does not require the disclosure of toxic effects and actually discourages companies from studying and disclosing the hazards of each chemical. As a result, the vast majority of industrial substances in wide use today have unknown toxic effects (Baker, 2009). The most vulnerable of society to the toxins released into the environment are young children. Sufficient toxic perturbation during a child's rapid and diverse development leads to adverse health outcomes and delayed human capital accumulation (Sheldon and Cohen-Hubal, 2009; Paustenbach, 2001; Hewitt and Tellier, 1998; Wergeland and Strand, 1997; Altshuler et al., 2003). Given the immense and growing variety of environmental toxins with unknown effects, exploratory studies like this one can provide

[1] In 2007, the US Environmental Protection Agency developed and began implementing ToxCast as a way to collect and analyze the effects of potentially toxic chemicals. The year 2009 saw the completion of the first phase, the profiling of approximately 300 previously researched pesticides. Current work is under way to profile the risks of hundreds more.

important etiological clues to generate hypotheses for observed negative health and human capital outcomes (Root and Emch, 2010).

This study exploits the Cebu Longitudinal Health and Nutrition Survey (CLHNS) that has taken place since 1983 in Metropolitan Cebu, Philippines. Collection of health data began while respondent mothers were pregnant and their children were in utero in 1983-1984 (at approximately 6 to 7 months of pregnancy). Following the child's birth, additional surveys were conducted bi-monthly for the first two years of life and periodically afterwards until the children were in their early to mid-twenties in 2005. This health data is paired with unique geographic data indicating the locations of industrial polluters, mines and agriculture to characterize the sources of contamination ranging from airborne particulate matter to groundwater pesticides. The transportation of contaminants from the source to the local environment of the individual is described using wind patterns, precipitation, topography and local infrastructure. High frequency observations of wind direction, wind speed and rainfall produce spatial and temporal variation in the sources to which an individual is exposed via the air; detailed topographic and infrastructure data such as watershed boundaries, elevation, soil type and piped water networks produce spatial variation in an individual's exposure via water. These geographic factors influencing the transport of the contaminant from the source to the individual will be used as instrumental variables to identify the causal impacts of environmental exposures on health. Combining the unique geographic data describing the source locations and transport of pollution with the longitudinal characteristic of the CLHNS survey enables the analysis of both short and long-term effects of contamination occurring during pregnancy and early-life.

Health, a form of human capital, is fundamentally multidimensional, one of the reasons it is difficult to measure. Many potential measures of health are measured with error that is systematically correlated with individual characteristics that influence health, such as income and education. Anthropometrics such as height are not subject to systematic measurement error (Strauss and Thomas, 1998). This study will use height as the measure of health because, unique amongst anthropometric measures, it has been shown to reflect early-life inputs and it is programmed by an early age. Epidemiological evidence shows that achieved stature between the ages of two and three is strongly correlated with adult height, meaning that early investments in children are particularly impactful (Martorell and Habicht, 1986; Ruel et al., 1995; Rivera et al., 1995; Schroeder et al., 1995; Haas et al., 1995; Alderman et al., 2006; Hoddinott and Kinsey, 2001). Moreover, height is positively correlated with cognitive achievement and schooling outcomes and predicts economic productivity and mortality, among others. This link between height and human capital has been thoroughly established in the literature, particularly in lower income developing country contexts like Metropolitan Cebu (Strauss and Thomas, 1998; Schultz, 1990). Regarding the particular context and timeframe of the current study, the effect of a 1 centimeter increase in height is associate with a nearly 1 percent increase in wage rate in the Philippines (Haddad and Bouis, 1991; Foster and Rosenzweig, 1993). Therefore, in developing nations, and the Philippines in particular, height is a marker of health and human capital, and height is affected by numerous types of early-life insults, including the immense variety of environmental toxins (Alderman et al., 2006; Altshuler et al., 2003). Utilizing height as a marker of health and human capital, this study examines the long-term effects of exposures to environmental contaminants during the early, vulnerable stages of life.

Numerous studies across a variety of fields have examined the effects of environmental toxins on health. However the current study is unique in jointly estimating the effects of multiple early-life exposures occurring in non-disaster settings on long-term health while considering behavioral compensation. A number of studies utilizing data from the Center for the Health Assessment of Mothers and Children of Salinas

(CHAMACOS) have examined the health effects of mother's and children highly exposed to agricultural pesticides in one of the richest agricultural areas on earth. Health outcomes and biomarkers of toxin exposures collected show an increased the likelihood of infant mortality and diminished development across multiple dimensions of human capital such as cognition (Eskenazi et al., 2004, 2010; Fenster et al., 2006; Marks et al., 2010). Roy et al. (2011) provides a unique analysis of the combined effects of exposure to multiple toxins, showing that the combined exposure to heavy metals (arsenic and lead) as well as biological fecal coliforms resulting in iron deficiency anemia interacts with lead exposure to damage cognitive abilities. However, each of these studies fail to account for the non-random assignment of exposure as well as other determinants of health such as behavior. Studies in the economic literature are careful to address the issue of non-random assignment of exposure. Almond et al. (2009a) examines the effects of pre-natal exposure to radioactive fallout from the 1986 Russian Chernobyl disaster on long-term cognitive ability of Swedish children. Meteorological conditions caused Sweden to receive roughly 5 percent of the Caesium fallout with significant geographic dispersion. Interestingly, the analysis shows no damage to health, but cognitive ability as manifested in academic achievement is negatively affected. Analysis of behavioral compensations indicate that parental responses vary by education and affect the child's human capital development. Ebenstein (2012) examines non-disaster exposures utilizing water and air quality measures from the early 2000s in combination with digestive cancer mortality rates between the years 1991 and 2000 in China. Rainfall and river length are used as instruments and the results show that the 1970s industrial boom increased pollution and digestive cancer mortality. Other studies have examined the short-term effects of biologically contaminated water (Galiani et al., 2005; Gamper-Rabindran et al., 2008; Bennett, 2011) as well as air pollution resulting from fuel combustion (Currie et al., 2009, 2011; Schlenker and Walker, 2011). Developing nations are usually host to water quality studies because of variation in access to piped water, which is used as a proxy for water quality. The paucity of air quality data in developing countries has resulted in few studies relating air quality to health.[2] Examining the impacts of environmental toxins in developing countries is critical because both air and water pollution are often more prevalent and health is generally poorer.

Because of the immense and growing variety of contaminants arising from economic activities and their unknown and interactive effects with each other, biological contaminants and behavior, new methods are needed to describe the effects of environmental contamination on human health (Paustenbach, 2001). One of the contributions of this study is the joint estimation of the effects of exposures to various contaminants. Individuals are not exposed to one contaminant in a vacuum, rather real-life, daily exposures occur to a variety of contaminants and the presence of one contaminant in the environment is often correlated with the presence of others (Georgopoulos, 2008; Barrett et al., 2010). Findings indicate that separately estimating the effects of exposure misidentifies the impacts to height. When separately estimated most types of exposures exhibit a significant negative effect on health. However, when jointly estimated only a select few, industrial and mining emissions transported via water, exhibit significant negative effects. Additionally, this study contributes to the understanding of environmental toxins through the use of detailed meteorologic, topographic and infrastructure factors of contaminant transport as sources of exposure variation exogenous to residential sorting and compensating behaviors. Distance proxies for exposure and is instrumented to correct for systematic differences between those residing close and far from pollution sources. For exposures transport by air, high frequency wind direction, wind speed and rainfall data are used as instruments. Exposures by water are instrumented by watershed boundaries, soil

[2] Almond et al. (2009b) does examine air quality measures near China's Huai River however the study focuses on the policy of free heating north of the river and does not consider the effects on health.

types, pipe age, well depth and rainfall. By utilizing factors of contaminant transport as instruments, jointly considering multiple exposures, and accounting for compensating behaviors, this study provides insights regarding the health and human capital effects of exposure to environmental toxins. Findings indicate that height throughout life is negatively impacted by early-life exposure to multiple environmental toxins, particularly industrial and mining emissions via water. The magnitude of the effects of early-life exposure diminish with age though they remain significant in adulthood. Furthermore, human capital is negatively affected by the combined exposure to toxins released by economic activities and biological contaminants, confirming Roy et al. (2011). Additionally, parental compensating investments are generally effective in reducing the impacts of environmental exposures.

The paper will proceed as follows. First, the health production function will be developed and discussed including how environmental exposures enter to affect health in section 4.2. The following section 4.3 will describe the empirical implementation. The Metropolitan Cebu context of the study as well as the data from the Cebu Longitudinal Health and Nutrition Survey containing health and human capital information will be discussed. Additionally, the data used to characterize the transport of the contaminants will be introduced and the empirical strategy explained. In section 4.4 the results are described and discussed. Finally, section 4.5 concludes this chapter.

4.2 Model

4.2.1 Health Production Function

Human health involves interactions among multiple scales of biological organization that are affected by various environmental factors (Georgopoulos, 2008). In addition to environmental factors, there are likely feedbacks between health and economic resources - limited resources curtailing health investments and resulting poor health outcomes feeding back to affect economic resources (Strauss and Thomas, 2007). While most dimensions of health change over time, containing both a stock and flow component, the focus of this study will be on height which is fixed in adulthood. Height can be thought of as a durable good resulting from early-life investments (Martorell and Habicht, 1986; Ruel et al., 1995; Rivera et al., 1995; Schroeder et al., 1995; Haas et al., 1995; Alderman et al., 2006; Hoddinott and Kinsey, 2001). Presented below is a general model of health production and consumption which builds upon the model presented in Strauss and Thomas (2007).

First, consider the health production function for the individual where time is treated as discrete and denoted with t:

$$\theta_{i,t+1} = \theta\Big(I_{i,t}, I_{i,t-1}, ..., I_0; E_{i,t}, E_{i,t-1}, ..., E_{i,0}, A_{i,t}, A_{i,t-1}, ..., A_{i,0}, B_i^H, \mu_i, \mu_{i,t}, \mu_{i,t-1}, ..., \mu_{i,0}\Big)$$

$$\theta_{i,t+1} = \theta\Big(\mathbf{I_{i,t}}; \mathbf{E_{i,t}}, \mathbf{A_{i,t}}, B_i^H, \mu_i, \boldsymbol{\mu_{i,t}}\Big) \tag{4.1}$$

$\theta_{i,t+1}$ denotes a particular health outcome at time $t+1$. In this case the health outcome of interest is height. Note that $\theta_{i,t+1}$ is a function of inputs dating from time period 0 to time period t, or in other words, the result of production is observed in the following period. $\theta_{i,t+1}$ depends on a vector of health inputs and behaviors in the current period, $I_{i,t}$, and all past periods, $I_{i,t-1}, ..., I_{i,0}$, with $\mathbf{I_{i,t}}$ denoting the full history of inputs from period $t = 0$ to t. These inputs are under the control of the individual. The parameters to the right of the semicolon affect the technology or the shape of the health production function. $\mathbf{E_{i,t}}$ denotes the vector of the full history of environmental factors. The shape of the health production function will vary with the vector of the history of socio-demographic characteristics $\mathbf{A_{i,t}}$, as well as the time-invariant components of family background that affect health (such as parental health and genetic endowment), B_i^H. μ denotes a time-invariant component of the health technology that is unobservable to the econometrician. $\boldsymbol{\mu_{i,t}}$ denotes the history of time varying unobservable heterogeneity.

Those voluntary inputs in the body's productive processes which the individual controls have been denoted $\mathbf{I_{i,t}}$ and the environmental factors not chosen as inputs by the individual are denoted $\mathbf{E_t}$. Not all the involuntary environmental factors $\mathbf{E_{i,t}}$ are used in the body's processes, instead many are toxins. Air is contaminated by, among others, vehicle exhaust and emissions from industrial production. Previous studies focus on relating one pollutant to health outcomes such as birth weight and infant mortality (see (Coneus and Spiess, 2010; Currie and Walker, 2011; Currie et al., 2009, 2011; Schlenker and Walker, 2011). However, mounting evidence suggests that the presence of multiple types of contaminants in the environment is correlated (Barrett et al., 2010; Greenstone and Hanna, 2011). Detrimental environmental factors are denoted $\mathbf{E_{i,t}}$:

$$\mathbf{E_{i,t}} = \left\{\boldsymbol{\sigma_{i,t}}, \boldsymbol{\delta_{i,t}}\right\}$$

The environmental factors of interest in this study are denoted $\boldsymbol{\sigma_{i,t}} = \{\sigma_{i,0}, ..., \sigma_{i,t}\}$. Moreover, as demonstrated in Roy et al. (2011) there is a potential interplay between biological and chemical contaminants in the environment. Roy et al. (2011) show that exposure to lead in combination with iron deficiency anemia - generally a result of parasitic worms accompanying fecal contamination - produce negative effects to human capital. Biological and non-biological contaminants are separately denoted $\boldsymbol{\delta_{i,t}}$ and $\boldsymbol{\sigma_{i,t}}$ respectively.

Revising equation (4.1) results in the following:

$$\theta_{i,t+1} = \theta\Big(\mathbf{I_{i,t}}; \boldsymbol{\sigma_{i,t}}, \boldsymbol{\delta_{i,t}}, \mathbf{A_{i,t}}, B_i^H, \mu_i, \boldsymbol{\mu_{i,t}}\Big) \tag{4.2}$$

A common approach to estimating this model is to assume that the health outcome in the previous period is a sufficient statistic for all prior health outcomes and inputs, reducing the empirical problem to explaining flows in health and not the evolution of the stock over the entire life course (Strauss and Thomas, 2007). However, for some questions, including the examination of the long-term impacts of early-life exposures, this strategy is inappropriate. One of the key ideas of the fetal origins literature is that the health effects of fetal conditions can have a potentially long latency period (Barker, 1995). Therefore, if previous period health does not accurately reflect the fetal conditions because of a long latency period, then the etiology of the observed health outcomes will be misattributed.

Alternatively, the current study reduces the number of time periods and employs variables which describe a portion of the history of inputs and factors. The time periods considered are $t = fetal$, later life as $t = adult$, and the in between period as $t = mid$. Thus, equation (4.2) can be rewritten as:

$$\theta_{i,adult} = \theta\Big(I_{i,fetal}, I_{i,mid}; \sigma_{i,fetal}, \sigma_{i,mid}, \delta_{i,fetal}, \delta_{i,mid}, A_{i,fetal}, A_{i,mid}, B_i^H, \mu_i, \mu_{i,fetal}, \mu_{i,mid}\Big) \tag{4.3}$$

The key is determining what information will describe the chosen inputs, environmental and socio-demographic factors during the fetal and mid periods. Focusing on height as the outcome of interest makes the task much simpler. Because evidence shows that achieved stature at age two is strongly correlated with adult height, the problem of finding information describing the variety of inputs in the health production function for the fetal and mid periods is focused to the relatively short timeframes of pregnancy and early childhood from birth until age two (Martorell and Habicht, 1986; Ruel et al., 1995; Rivera et al., 1995; Schroeder et al., 1995; Haas et al., 1995; Alderman et al., 2006; Hoddinott and Kinsey, 2001). The benefit of this specification is that it allows for the explicit examination of inputs and factors at particular points of interest throughout the life course.

4.2.2 Environmental Quality

$\sigma_i = \{\sigma_{i,1}, ..., \sigma_{i,J}\}$ is a vector of $j = 1, ..., J$ types of environmental toxins to which individual i is exposed. The amount of the environmental toxin to which the individual is exposed is a function of the amount emitted from the surrounding sources $s^n = \{1^n, ..., S^n\}$ part of an industry $n^j = \{1^j, ..., N^j\}$ that contributes to the levels of contaminant $j = \{1, ..., J\}$ and the transport of the toxin from the source to the individual. Optimally, information regarding the contaminant levels in the individual's environment would be available however, in many contexts (including the current one in question) contaminant levels are not observed either in general or for the specific location. In this instance, many studies adopt a distance proxy for contaminant levels. A proxy for each $\sigma_{i,j}$ denoted $\tilde{\sigma}_{i,j}$ is adopted and constructed of industry output levels and the distances from each source to the individual. The output of industry n^j releasing contaminant j into the environment is denoted α_{n^j} and is used as weights. The distance from each source s^n of industry n^j contributing to contaminant levels j to the individual is denoted d_{i,s^n}. The sum of the inverse distances weighted by industry output is the proxy for contaminant levels to which the individual is exposed:

$$\tilde{\sigma}_{i,j} = \sum_{n^j=1}^{N^j} \sum_{s^n=1}^{S^n} \frac{\alpha_{n^j}}{d_{i,s^n}} \tag{4.4}$$

Many previous studies have employed distance as a proxy for exposure (see Currie and Walker (2011); Currie et al. (2011)) however distance may be correlated with unobservable determinants of health. For instance, if environmental quality is capitalized into housing prices then proximity to a number of sources of pollution will also be correlated with income. For this reason additional factors of transport are employed as instrumental variables. The determining factors of transport include the media, Q, relevant topography between the sources s^n of industry n^j and the individual, $T_{i,j}$, meteorology such as wind direction, speed and rain influencing the path between the sources, $M_{i,j}$, and infrastructure along the same path between the sources and the individual, $P_{i,j}$.

$$\sigma_{i,j} = \tilde{\sigma}_{i,j} = f(Q, T_{i,j}, M_{i,j}, P_{i,j}) \text{ for } j \in \{1, 2, ..., J\} \tag{4.5}$$

The purpose of employing wind direction, wind speed, rain, watershed boundaries, elevation, soil, other topographical features and infrastructure including the piped water network describe the transport of the contaminant from the source to the individual and produce plausibly exogenous spatial and temporal variation in exposure. The following section will describe the context of Metropolitan Cebu and provide greater detail on the factors of transport and the data that is employed to estimate the effects of early-life exposures to environmental toxins.

4.3 Empirical Implementation

4.3.1 Cebu, Philippines

Metropolitan Cebu is located on the island of Cebu in the Central Visayas region, otherwise known as Region VII, of the Philippines (see figure 4.1). An island mountain range runs down the middle of the island and the Metropolitan Cebu area, the only major population and economic hub on the island, is located in the center of the island on the southeastern side of the mountain range (see figure 4.2). In 1983 there were five cities and five municipalities in Metropolitan Cebu - Cebu City, Mandaue City, Talisay City, Lapu-lapu City, Naga City, Consolacion, Liloan, Cordova, Minglanilla and Compostela (see figure 4.3). The Cebu Longitudinal Health and Nutrition Survey, which provides the health and human capital data for this analysis, randomly sampled 33 barangay - or wards, which are the smallest administrative division in the Philippines - in 8 of the aforementioned cities and municipalities, all but Minglanilla and Compostela (see figure 4.4).

The Metropolitan Cebu area is the only area of high population and economic density on the island. This relative isolation enables the description of environmental contamination to be complete with a description of economic activity in the metro area. Over the past few decades the area has experienced increasing amounts of industrial activities, culminating in the recent description from Environmental Management Bureau regional director that Cebu today is like Manila of the 1970s and 1980s, a city and time of famously high levels of pollution.[3] By recent count, approximately 1000 industrial establishments are located in the province of Cebu, mainly concentrated in Cebu City, Mandaue and Lapu-lapu. However, high levels of pollution emanate from less dense areas such as Naga where a large, coal-fired power plant and a cement plant generate a significant portion of airborne contaminants in the area. The Clean Air Act of 1999 and the Clean Water Act of 2004 in the Philippines followed a series of ineffectual legislations during the 1990s aimed at protecting the natural resources. Prior to these laws (whose effectiveness are still uncertain), the estimated annual losses due to water pollution in the Philippines are over 1.3 billion US dollars (The World Bank, 2003) and the health costs alone of air pollution total approximately half a billion dollars annually (The World Bank, 2002).

The following sections contain descriptions of first, the Cebu Longitudinal Health and Nutrition Survey data used to describe health and human capital, second the geographic data used to describe the sources of environmental toxins, and third the transport of the toxins from the source to the individuals in the survey. The survey data employed is publicly available however the geographic data is private and

[3] Allan Aranguez, Environmental Management Bureau, Region VII, quoted in Parco, B. Metropolitan Cebu's air quality as bad as Manila's, Cebu Daily News, June 2008.

was compiled from a variety of governmental and non-governmental agencies with data sharing agreements agreed upon separately for each agency.[4] These agencies include the Provincial Planning and Development Office (PPDO), PhilGIS.org, the Environmental Management Bureau (EMB), the Provincial Mines Office (PMO), the Metropolitan Cebu Water District (MCWD), the National Climatic Data Center (NCDC), the Water Resources Center of the University of San Carlos (WRC), the Information Services Offices of the cities and municipalities in Metropolitan Cebu (ISOs), and the Directories Philippines Corporation (DPC). Data from the PPDO and PhilGIS.org include numerous geographic information system (GIS) maps of administrative boundaries, watershed boundaries, soil types, land use, roads as well as satellite imagery of the area. Databases of current polluter permits was provided by the EMB and the PMO provided information on the location and operation dates of small and large scale mines in the province. GIS maps of the piped water network and the installation dates of each pipe section were obtained from the MCWD. The NCDC and WRC provide frequently collected historical meteorology data including wind direction, wind speed and precipitation. From the ISOs and the DPC information on the existence, locations and industries of companies during the early to mid-1980s was obtained.

Cebu Longitudinal Health and Nutrition Survey

The Cebu Longitudinal Health and Nutrition Survey (CLHNS) randomly sampled 33 barangay (17 urban and 16 rural) in Metropolitan Cebu in order to form a cohort of pregnant women (see figure 4.4). Barangays are basically neighborhoods and are the smallest administrative district in the Phillipines. The 33 sample barangay contained in total roughly 28,000 households in 1982, all of which were canvassed in search of pregnant women. Women of the selected barangays who gave birth between May 1,

[4] Generally each agreement prohibits sharing and redistribution.

1983, and April 30, 1984, are included in the baseline sample taking place during the 6th or 7th month of pregnancy. In total 3,327 women were surveyed at baseline and at birth 3,122 were resurveyed (attrition due to migration), though 60 were either stillbirths, miscarriages or deaths within the first week. Following the child's birth, the mother-child pair was resurveyed every two months for the first two years of the child's life, and then in 1991, 1994, 1998, 2002, and 2005. In each sample barangay informants were stationed who reported births to survey interviewers who then performed the birth survey and collected the measures of birth length, weight and others (Feranil et al., 2008).

Key to this study are extensive and frequently collected anthropometric measures, information about the household's water source, measures capturing behavior related to child health, and community characteristics. Table 4.1 gives basic summary statistics of the sample of mothers, fathers, water use characteristics, the children's health at birth and in adulthood, household characteristics and attrition. Anthropometrics such as height, weight and arm circumference were collected for women beginning with the baseline survey and for children beginning at birth. The summary statistics in Table 4.1 show that both mothers and their children are relatively small. Mothers and fathers in the sample are young, average age 26 and 29 respectively. The majority of mothers in the sample have only an elementary or less education. The reported amount of smoking and drinking during pregnancy is 14 and 8 percent of the sample, while consumption of pre-natal vitamins indicating behavior of the mother aimed at improving the health of their unborn child is fairly high at 58 percent of the sample. There is a relatively small number of miscarriages and stillbirths in the sample, 2%, and approximately 12% of the sample children are born weighing less than 2500 grams. Behavioral measures related to child health are captured in the survey such as breastfeeding and other infant feeding patterns, mother's employment, and income. Measures of the index child's health upon reaching adulthood show an average height of 157 centimeters, average weight of 51.32 kg and an average BMI of 20.71, indicating that the sample is rather small. Additional biomarkers such as C-Reactive Protein, a protein in the blood which rises in response to inflammation and is a risk factor in cardiovascular disease, show that 11% of the sample exhibits elevated levels. The measures of human capital collected in 1994 - which are not comparable across surveys - demonstrate that the average non-verbal IQ score is 65 on a scale from 0 to 100 and the average math test score is 16.65 on a corrected scale from -20 to 60 (or equivalently 36.65 on a scale from 0 to 80). Hourly earnings of survey children in 2005 is 30.74 pesos on average.[5]

Regarding water source, in each survey the respondents were asked questions about their main water source - piped water, wells, other groundwater sources such as rivers - as well as the amount of time spent in traveling to the source. Because only 1 percent of the sample report mineral or bottled water as their main water source, inhabitants of Metropolitan Cebu during the early 1980s appear to only have two basic choices regarding their water: piped and groundwater. Furthermore, the household's main water source is located within the barangay at a mere 3 minute walk from the home.

Table 4.1 also shows that the sample is fairly mobile. A significant portion of the sample attrits at some point throughout of the nearly 3 decades of the survey, though a large portion only temporarily attrit, 17%. Migration patterns during the first years of the child's life, the exposure period, indicate that most migration is from rural to rural areas or urban to urban areas. If general levels of contamination are thought to be higher in urban relative to rural, this as well as the small amount of migration from urban to rural or rural to urban gives preliminary evidence that

[5] In 2005 this equated to roughly 60 US cents. Clearly this is quite low however because the earnings information includes individuals that only work in home production or that only work occasionally and report monthly or yearly earnings the average hourly earning is pulled towards zero. The maximum value of hourly earnings is 830 pesos, which in 2005 equated to 15 dollars an hour.

migration does not occur in response to exposure to pollution. Table 4.2 shows the sample population by city and barangay at baseline in Metropolitan Cebu. Nearly 47% of the sample resided in Cebu City, and 76% of the sample population resided in urban barangays.

Air Quality

Air pollution in the Philippines contributes to respiratory illness totaling 62% of all illness in the country, a statistic driven mainly by the two largest urban areas in the Philippines - Manila and Cebu.[6] In general, the sources of air pollution in the area of Metropolitan Cebu can be divided into stationary point sources and mobile sources, and by type of emissions. Stationary point sources are immobile structures, facilities or installations such as power and manufacturing plants. From the Environmental Management Bureau (EMB) a database of each industrial polluter by type (air, water, hazardous material) and industry dating back to 1999 is obtained.[7] This does not provide a description of stationary sources during the exposure period of 1982-86 when the cohort children were younger than 2. However, phonebooks from 1982, 1983, 1984, 1985 and 1986 obtained from the Directories Philippines Corporation (DPC) contain information regarding the existence, location and industry of companies in Metropolitan Cebu. By using the EMB data to determine which types of companies would have needed pollution permits and applying that to the companies that existed during 1983-86, the industrial stationary sources of pollution during the early-life of CLHNS cohort children is determined Figure 4.5 shows the locations of these sources of pollution.

Industries and stationary point sources are divided by type of emission with the

[6] See the Regional State of the Brown Environment Report of 2010, produced by the Environmental Management Bureau of the Department of Environment and Natural Resources in Region VII, for additional information.

[7] The early years of this list are relatively sparse, while the later years contain information on numerous polluters from various industries.

number of sources per industry and emission type displayed in table 4.3. The first type of emission specified for this study includes carbon monoxide (CO), nitric oxides (NO_x), sulphur oxides (SO_x), and particulate matter aerosols. Industries emitting particulate matter, carbon monoxide, nitrogen oxides, and sulfur oxides totaled 150 firms/plants in the Metropolitan Cebu area, with 17 of those being major producers as reported by local planning and development commissioners. Metropolitan Cebu during the early 1980s was home to a number of food and beverage, metal and concrete manufacturing plants. Each of these types of industries as well as the Mactan International airport[8] and large open mines[9] emit particulate matter, carbon monoxide, nitric oxides, sulfur oxides and to a lesser extent methane.[10] The second type of airborne emission is volatile organic compounds (VOCs). VOC emitting industries including pharmaceutical, chemical, furniture, plastic and rubber manufacturing totaled 149 during the early 1980s.[11] The final type of airborne contaminant in the Metropolitan Cebu environment is heavy metal and the total number of sources 25. Among the emitters of heavy metals are two coal fired power plants operating for multiple decades, glass manufacturers and open gold mines.[12]

Mobile sources of air pollution are powered by oxidation or reduction reactions such as carbon based fuel combustion (The Environmental Management Bureau,

[8] The Mactan International airport is located on the island of Lapu-Lapu and has existed since the mid 1960s.

[9] The Carmen Copper mine, a large open mine owned by Atlas Mining, opened in 1955.

[10] See Roundtable (2010); The United States Environmental Protection Agency (EPA) (2008a); The International Finance Group of the World Bank (IFG) (1998b,a); The National Pollutant Inventory (NPI) (1999); The United States Environmental Protection Agency (EPA) (2003); van Oss and Padovani (2003); Penner et al. (1999); The World Bank (1998).

[11] See The International Finance Group of the World Bank (IFG) (1998b); The United States Environmental Protection Agency (EPA) (1998b,a, 2008b); The National Pollutant Inventory (NPI) (1999).

[12] See The United States Environmental Protection Agency (EPA) (2008a); Engineering (2011); The International Finance Group of the World Bank (IFG) (1998a); The United States Environmental Protection Agency (EPA) (2008a).

2010). These vehicles are the major sources of carbon monoxide, ozone, particulate matter, nitrogen oxides, and lead. The types of vehicles in Cebu range from motorcycles to cars and taxis to jeepneys - a poplar mean of public transportation made from left over US military jeeps after World War II. To this day, almost all jeepneys as well as trucks, buses and utility vehicles run on diesel fuel, a main source of fine particle and nitrogen oxide emissions. Furthermore, lead was not eliminated from gasoline until 2001 in the Philippines. The detrimental effects of lead - ranging from neurological disorders to cardiovascular disease - were not recognized in the Philippines until the 1990s, and in 1993 the lead content in gasoline began to be phased out until being completely eliminated in 2001 (The World Bank, 2002). Registration of motor vehicles is relatively new in the Philippines and as such information regarding the number of motor vehicles during the time frame of 1983-86 is nonexistent. However, traffic flows are estimated using a standard gravity model incorporating relative populations of barangays from the 1980s census collected from the National Statistics Office (NSO) and supplemented with 1980-85 zoning information from the Information Services Offices of the various municipalities of Metropolitan Cebu (ISOs) . Supplementing the standard gravity model of traffic flows with zoning information - the portion of the barangay zoned as commercial or industrial versus residential and open - essentially incorporates information about commuting flows between each barangay (figure 4.6 shows the road network in Metropolitan Cebu).[13]

Water Quality

The provision of clean water is a critical problem throughout the Philippines - the second largest source of illnesses - though much more so in urban population hubs such as Metropolitan Cebu. Stationary point sources of pollution affecting the amount of toxins in the soil and water are classified into three groups and described in table

[13] The techniques of Jung et al. (2008) and Fernandez (2008) are employed to estimate traffic flows.

4.3: industrial, mining and agricultural. Industrial manufacturers of pharmaceuticals, chemical, fertilizers, plastic and rubber are known to emit contaminants into the groundwater (US EPA 1998; US EPA 2008; International Finance Group of the World Bank 1998). 67 firms/plants of these industries existed in Metropolitan Cebu during the early 1980s and 8 of the 67 were major polluters (the locations of these sources is obtained from the DPC and ISOs data). Figure 4.5 shows the locations of industrial polluters in red (not separated by industry and thus includes polluters emitting to the air as well as the water). As with sources of industrial air pollution the locations and industry information of point sources of water pollution is obtained from a combination of data from the EMB and the DPC. Mining causes acid rock drainage, where sulfides oxidize to form an acid effluent which leaches metals from existing rocks to contaminate the groundwater. Additionally, heavy metals such as mercury, used in processing are emitted in wastewater. 22 large and small scale mines existed during the early 1980s in Metropolitan Cebu, the majority of those copper mines. One of the copper mines, Carmen Copper owned by Atlas Mining, is very large and open. Other types of mines include clay, coal, gold and silver. Mines in the Metropolitan Cebu area are displayed in figure 4.7 in green. Information on the location, type and operating dates of Metropolitan Cebu mines is obtained from the Provincial Mines Office (PMO). In addition to toxins released by industrial processes and mining, the use of pesticides in agriculture is a major source of water contamination in Metropolitan Cebu. Agricultural presence in Metropolitan Cebu is obtained from 1980s land use GIS maps from the Provincial Planning and Development Office (PPDO). Figure 4.8 shows the different types of land use throughout Metropolitan Cebu. Reports from the Department of Agriculture (DA) indicate that pesticide and fungicide use is common for corn, mango and sugarcane, and because of coconut's rough outer shells no pesticides or fungicides are used. Furthermore, the major pesticides and fungicides employed are: carbofuran (one of the most toxic pesticides - banned in the EU and Canada), malathion (an organophosphate associated with behavioral disorders and neurodevelopment), mancozeb (a carbamate with thyroid and carcinogenic effects), fipronil and formetanate (acute toxicity and unknown long-term effects).

Factors of Transport

The variety of stationary and non-stationary sources of air and water pollution not only impact the presence of toxins in the immediately surrounding areas but also contaminant levels at more distant locations. Meteorology, topography and infrastructure dictate the transport of the contaminant from the source. Airborne contaminants are transported by wind patterns from the source to potentially distant locations and rainfall collects and remove particles from the air. Topographical features such as watershed boundaries, rivers and accumulation zones (areas where water accumulates before reaching a river or the ocean) dictate the transport of waterborne contaminants. Furthermore, soils differ in their ability to absorb and decompose contaminants thereby affecting the amount of toxins in the soils surrounding piped water and non-piped water sources such as wells. In describing these factors in greater detail, the factors of airborne transport will be discussed first followed by the factors of water transport.

Prior to considering topographic, meteorologic and infrastructure factors of transport the distance between the source of pollution and the individual is obtained from GPS coordinates of sources and the centroids of the individual's barangay. Following distance, the first component of air transport is wind direction. Wind direction has a very clear implication for the transport of contaminants; when the source of pollution is upwind in the same direction as the wind, the contaminants will be transported to the individual's local environment. Figure 4.9 gives a basic description of this showing point sources of pollution as red dots, sample barangay highlighted in yellow and the direction of wind given by the arrow (with North 0 degrees, East 90 and so on, the figure shows the wind blowing at approximately 160 degrees). Figure 4.10 gives a kernel density plot of wind directions for the two seasons in Cebu - the Amihan and the Habagat - from hourly wind observations obtained from the National Climatic Data Center (NCDC). Table 4.4 presents the percent of time the wind blows in certain directions, illustrating that variation exists despite dominating winds. The Amihan is dominated by cool northeast winds, while during wet season known as the Habagat the wind originates in the southwest. Furthermore, Metropolitan Cebu is oriented on an axis running from the southwest to the northeast, meaning that these dominating wind patterns sweep across Metropolitan Cebu from the northeast during the Amihan and from the southwest during the Habagat. Wind speed generally mitigates the effects of distance such that when wind speeds are high contaminants are carried a greater distance (US EPA 2008). Hourly observations of wind direction and wind speed from the (NCDC) provide high frequency information regarding the influence of wind on the individual's exposure. Rainfall data is collected from the Water Resources Center (WRC) of the University of San Carlos with the yearly patterns are displayed in figure 4.11. Wind direction, wind speed and rain are used to instrument distance, diminishing the relative weights of close, obvious sources contributing to total exposure and isolating variation uncorrelated with the error.

Rainfall, with data from the WRC, similarly determines the transport of contaminants via water. Rainfall increases the flow of groundwater towards the ocean, cleansing the consumer's sources of drinkable water. The flow of water before reaching the ocean is dictated by various topographical features. Topographical GIS maps are obtained from the Provincial Planning and Development Office (PPDO) and satellite imagery of digital elevation model are obtained from PhilGIS.org. The first topographic feature to note that dictates transport is watershed boundaries. The contaminant content within the soil and water are only affected by polluters located within the watershed within which water flows in a predictable fashion and does leave except to the ocean and does not enter except by rain. The second topographic feature to incorporate is elevation, clearly locations are only contaminated by polluters at higher elevation. Additionally, satellite imagery is incorporated using the hydrology tools in ArcGIS to identify the third topographic feature to consider: accumulation zones, or areas where the topography dictates that surface water will flow until reaching the river or ocean. Combining this topographic data with the locations of polluters yields precise descriptions of the flows of contaminants in the water and is implemented similarly to watersheds with binary variables indicating whether the emissions from particular sources can flow to the area of the household's water source. Furthermore, GIS soil maps from the PPDO provide information on the types of soils in the area displayed in figure 4.13, which are the following: lugo clay, faraon clay (both standard and steep slope), beach sand, medellin clay, mandaue clay, baguio clay loam, hydrosol, and bolinao clay (both standard and steep slope). The sensitivity, or rapidity of the transmission of a toxin to the groundwater, of each soil type is ranked on properties of permeability, organic matter and clay content of the soils in the area. Permeability is controlled by the size and continuity of soil pores, the most permeable soils being sands and gravelly soils. Organic matter affects the binding and degradation of toxins in the soil while the higher the clay contact the greater the retention of toxins in the soil. Considering these properties, the most sensitive soil is beach sand and the least sensitive is faraon clay (Huddleston 1996). The city means of the soil flow index within watersheds contributing to the quality of the individual's water source is displayed in table 4.5.

Each of the topographic features as well as rainfall impact the transport of toxins via water to where the consumers obtain their water and characteristics of the consumer's source also impacts the quality. For non-piped sources surface water is more likely to be contaminated than water emanating from sources deeper in the ground because the soil can retain and degrade toxins. Therefore, of the survey household's non-piped sources rivers are the worst quality and deep wells the best. Table 4.5 displays the percent of city residents in the sample who obtain non-piped water from deep sources. Regarding piped sources, table 4.5 contains descriptive statistics of the Metropolitan Cebu Water District (MCWD) pipe network by city, including the age in years and the length of pipes. Piped water in Metropolitan Cebu is supplied by only the MCWD that was created by the Local Water Utilities Act of 1973.[14] Figure 4.14 displays the piped water network that existed in 1986 when the children of the CLHNS were age 2. Typically piped water is considered higher quality than non-piped water however it can be contaminated after treatment before reaching the household. This type of contamination occurs because of service interruptions which cause pressure variation and seepages within the pipes (LeChevallier et al. 2003). Service interruptions are frequent in this context even in 2005 after many investments and improvements when households averaged under 20 hrs per day of service (ADB 2005). Because of this feature of the MCWD network, seepages drawing toxins from the surrounding soil contaminate the water after treatment and before household consumption. Moreover, seepages are more likely to occur in older pipes in need of maintenance so the age of the pipes is incorporated as an instrumental variable. Because toxins are drawn from the surrounding soil the previously described topographic features such as watersheds, accumulation zones and soil types also affect the quality of piped water.

A graphical description of the process of piped water contamination is given in figure 4.12 where survey respondent's residence within the Mandaue watershed are shown in light yellow polygons, the river in blue, accumulation zones in gray, the

[14] The MCWD was built upon the 25.4 million Philippine pesos of infrastructure assets of the Osmena Waterworks System created in 1910. Infrastructure investments of 58 and 112 million pesos were invested in 1976 and 1983 respectively, followed by more large scale investments every few years. For additional information on the MCWD see their website at www.mcwd.gov.ph

pipe network in purple, wells in green and sources of pollution in red. This figure shows that some proximate polluters do not affect the quality of water because the accumulation zones send the emissions the opposite direction or the source is on the opposite side of the river. Similar to exposure by air, when exposure to pollution via water is measured solely by distance it is likely to be endogenous to systematic differences between the highly and less exposed. However, when watershed boundaries, elevation, accumulation zones, and soil sensitivity are used to instrument distance the relative weights of close, obvious sources contributing to total exposure are diminished and the variation uncorrelated with unobserved determinants of health is isolated.

4.3.2 Empirical Specification

A standard linear functional form is adopted for the health production function, simplifying interpretation and avoiding the specification pitfalls of instrumental variable estimation (Angrist and Krueger, 2001). Health outcomes are examined at various points in life - birth, age 1, age 2 and adulthood - so the number of time periods included in the production function changes. The equations below are linear forms of equation (4.3), illustrating the production function inputs determining health throughout life. Equation (4.6) shows the inputs in the production function for birth outcomes: I_1, δ_1, and A_1 are the chosen inputs, biological exposures and socio-demographic factors during pregnancy. Equation (4.7) is the estimation equation for health outcomes at ages 1 and 2, with the inputs in period 2 denoting either the first year of life or the first two years of life. Equation (4.8) is the estimation equation for health outcomes in adulthood, with the inputs in period 2 denoting the first two years of life.[15]

[15] Additional functional form specifications have been examined. The shape of most empirical relationships is linear, and in the few instances when a non-linear functional form may be more appropriate the estimated differences between the linear and non-linear models are negligible.

$$\theta_1 = \alpha + \sum_j \phi_j \tilde{\sigma}_j + \beta_1 I_1 + \psi_1 \delta_1 + \gamma_1 A_1 + \omega B^H + \epsilon_1 \tag{4.6}$$

$$\theta_2 = \alpha + \sum_j \phi_j \tilde{\sigma}_j + \beta_1 I_1 + \beta_2 I_2 + \psi_1 \delta_1 + \psi_2 \delta_2 + \gamma_1 A_1 + \gamma_2 A_2 + \omega B^H + \epsilon_2 \tag{4.7}$$

$$\theta_3 = \alpha + \sum_j \phi_j \tilde{\sigma}_j + \beta_1 I_1 + \beta_2 I_2 + \psi_1 \delta_1 + \psi_2 \delta_2 + \gamma_1 A_1 + \gamma_2 A_2 + \omega B^H + \epsilon_3 \tag{4.8}$$

Recall that $\tilde{\sigma_j}$ is the industry weighted measure of distance from the sources to the individual and each source of a particular industry contributes to the overall level of particular contaminant types $j = \{$CO - NO - SO_X - PM_{10}, VOCs, Heavy Metals, Traffic Emissions, Industrial Water, Agricultural Pesticides, Mining Water$\}$. Exposure measures of distance are standardized with mean 0 and standard deviation 1. Height, the main outcome of interest, is reported as a z-score determined by CDC standards. Therefore, an exposure coefficient of .1 means that a 1 standard deviation increase in the proxy of exposure increases the z-score of height by .1.[16] The distance proxy of exposure remains the same regardless of the time period however the instrumental variables incorporate the entire period of exposure prior to observation. For example, the distance proxy of exposure is the same for birth length and for adult height but when birth length is the outcome the instrumental variables incorporate the entire period of pregnancy and when adult height is the outcome the instrumental variables incorporate pregnancy and the first two years of the child's life.

[16] It is noteworthy that measures of exposure are only for one period. Although some households migrate within the first 2 years of the child's life and new polluters arise resulting in some temporal variation in exposure as measured and proxied by distance, the amount of variation is too small to separately identify the two period effects. One of the issues contributing to insufficient temporal variation in this distance measure of exposure is that often survey respondents are not followed so their migratory histories are incomplete.

Recall that I_1 = mother's consumption of pre-natal vitamins, I_2 = mother's education, A_1 = per capita household income during pregnancy, A_2 = mean per capital household income prior to age 2. Also note that robustness checks of which family background variables to include in $\boldsymbol{B^H}$ have been conducted considering mother's height, mother's age, father's age, mother's skin fold measurement, mother's BMI and others. The chosen specification includes mother's height, mother's age and father's age but different specifications produce similar results. Additionally, robustness checks have examined the inclusion of different geographic fixed effects - city, and city-urban/rural. The inclusion or non-inclusion of these geographic indicators do not alter the results and are not displayed in the following tables.

4.3.3 First Stage

The estimation of equations (4.6), (4.7) and (4.8) is performed by two stage instrumental variables, the first stage regressing the proxy of the individual i's exposure to environmental toxins of type j, $\tilde{\sigma}_{i,j}$, on the instruments $\boldsymbol{Z}_{i,j} = \{Q, T_{i,j}, M_{i,j}, P_{i,j}\}$:

$$\tilde{\sigma}_{i,j} = \boldsymbol{\pi}_j \boldsymbol{Z}_{i,j} + \eta_{i,j} \tag{4.9}$$

Recall that the set of instrumental variables selected for this study contains the media, Q, the topography between the sources s^n of industry n^j and the individual, $T_{i,j}$, the meteorology influencing the transport path, $M_{i,j}$, and the infrastructure, $P_{i,j}$. These instruments are fundamentally grounded in theory and are important determinants of exposure. For exposure to contaminants transported via air, $Q = \{air\}$, the instruments are wind direction, wind speed and rain denoted $M^d_{i,s,\tau}$, $M^s_{i,s,\tau}$, and M^r_τ respectively. τ denotes the high frequency observations of transport factors within the time period t. Recall from equation (4.4) that the proxy of exposure, $\tilde{\sigma}_{i,j}$, to environmental toxins of type j is the sum of the inverse distances between the individual and pollution sources weighted by the industry output of the sources, or:

$$\tilde{\sigma}_{i,j} = \sum_{n^j=1}^{N^j} \sum_{s^n=1}^{S^n} \frac{\alpha_{n^j}}{d_{i,s^n}}$$

Therefore, for types of exposure transported by air the first stage of the estimation is:

$$\begin{aligned} \tilde{\sigma}_{i,j} \quad = \quad & \pi_{1,j} \textstyle\sum_{\tau \in t} \tilde{\sigma}_{i,j} M^d_{i,s^n,\tau} + \pi_{2,j} \textstyle\sum_{\tau \in t} \tilde{\sigma}_{i,j} M^d_{i,s^n,\tau} M^s_{i,s^n,\tau} \\ & + \pi_{3,j} \textstyle\sum_{\tau \in t} \tilde{\sigma}_{i,j} M^d_{i,s^n,\tau} M^s_{i,s^n,\tau} M^r_{\tau} + \eta_{i,j} \end{aligned} \tag{4.10}$$

As an example, consider the simplified context of one pollution source, $s^n = \{1\}$, in one industry, $n^j = \{1\}$, contributing to the levels of one environmental toxin, j, to which one individual i is exposed. The proxy of exposure exposure is equal to $\tilde{\sigma}_{i,j} = \frac{\alpha_{n^j}}{d_{i,s^n}}$, the industry n^j output weighted distance between the individual i and the source s^n. If the bearing of the wind during the first hour $\tau = 1$ of the fetal development period is the same as the bearing between the source and the individual (i.e. the individual is downwind from the source) then $M^d_{i,s^n,1} = 1$. Therefore, $\sum_{\tau \in t} \tilde{\sigma}_{i,j} M^d_{i,s^n,\tau}$ essentially weights the exposure of individual i to source s^n by the amount of time spend downwind. Wind speed $M^s_{i,s^n,\tau}$ and rainfall M^r_{τ} are implemented as categorical variables which aggregate their magnitudes. Higher wind speeds disperse the contaminant at greater distances and for empirical implementation are divided into 5 categories: 0 kph, 1 to 3 kph, 3 to 5 kph, 5 to 10 kph and over 10 kph - the first category given the value of 0 and the last given the value of 4 (for information regarding the distribution over time and across categories see table 4.4). While falling, raindrops remove contaminants from the air and deposit them in the ocean. For empirical implementation, rainfall is divided into 6 categories: 0 mm, 0 to 1 mm, 1 to 3 mm, 3 to 5 mm, 5 to 10 mm, over 10 mm - the first category given the value of 0 and the last given the value of 5 (for information regarding the distribution over time and across categories see table 4.4). Each of the constructed measures in equation (4.10) - $\sum_{\tau \in t} \tilde{\sigma}_{i,j} M^d_{i,s^n,\tau}$, $\sum_{\tau \in t} \tilde{\sigma}_{i,j} M^d_{i,s^n,\tau} M^s_{i,s^n,\tau}$, and $\sum_{\tau \in t} \tilde{\sigma}_{i,j} M^d_{i,s^n,\tau} M^s_{i,s^n,\tau} M^r_\tau$ - are standardized with mean 0 and standard deviation 1. Table 4.6 displays the first stages of the instrumental variable regressions for exposure via air resulting in highly predictive estimates with large F-statistics.

Now consider the types of exposure transported via the water, $Q = \{water\}$. For waterborne toxins the factors of transport that are used as instruments are: the watershed boundaries and accumulation zones influencing the groundwater flow between the individual, i, and the source, s^n, T^{wa}_{i,s^n}, the soil flow index, T^f_{i,s^n}, the average age of the pipes or depth of the well supplying the individual i's water and influenced by source s^n, P^{pd}_{i,s^n}, and rainfall M^r_τ. Therefore, for types of exposure transported by water the first stage of the estimation is:

$$\begin{aligned} \tilde{\sigma}_{i,j} \quad = \quad & \pi_{1,j} \textstyle\sum_{\tau \in t} \tilde{\sigma}_{i,j} T^{wa}_{i,s^n} T^f_{i,s^n} + \pi_{2,j} \textstyle\sum_{\tau \in t} \tilde{\sigma}_{i,j} T^{wa}_{i,s^n} T^f_{i,s^n} P^{pd}_{i,s^n} \\ & + \pi_{3,j} \textstyle\sum_{\tau \in t} \tilde{\sigma}_{i,j} T^{wa}_{i,s^n} T^f_{i,s^n} P^{pd}_{i,s^n} M^r_\tau + \eta_{i,j} \end{aligned} \tag{4.11}$$

For illustration, consider again the context of one pollution source, $s^n = \{1\}$, in one industry, $n^j = \{1\}$, contributing to the levels of one environmental toxin, j, to which one individual i is exposed. The proxy of exposure exposure is equal to $\tilde{\sigma}_{i,j} = \frac{\alpha_{nj}}{d_{i,s^n}}$, the industry n^j output weighted distance between the individual i and the source s^n. First, sources of pollution outside of the watershed encompassing individual i's residence do not contribute to the level of toxins in the groundwater, in which case $T^{wa}_{i,s^n} = 0$. If the source s^n is located in the same watershed the accumulation zones derived from satellite imagery determine the contribution of source s^n to individual i's water. If the source s^n is proximate to the individual but because of the accumulation zones the groundwater flows away from the individual's residence, then $T^{wa}_{i,s^n} = 0$. If the accumulation zones within the watershed dictate that the groundwater flows from the source to the individual $T^{wa}_{i,s^n} = 1$. The sensitivity of the soil, T^f_{i,s^n} measuring the flow of the toxin to the groundwater, is an index between

0 and 2 and is calculated from the percent of area of the various soil types at higher elevations in the watershed encompassing the individual i's residence. If more of the watershed at higher elevations is composed of high sensitivity soils such as hydrosol and baguio clay loam, then T^f_{i,s^n} will be greater than the index value of watersheds composed of less sensitive soils such as bolinao and faraon clay.[17] For individuals that obtain their water from non-piped sources, $P^{pd}_{i,s^n} = 1$ if the source is shallow like a shallow well or a river. Shallow, non-piped water sources are at greater risk of contamination than deep sources because the soil filters and degrades the toxins. For piped sources, if the age of the pipes supplying the individual i is greater than the network average age then $P^{pd}_{i,s^n} = 1$. Old pipes are more susceptible to seepages introducing toxins into the piped water after treatment but before consumption. As with exposures transported via air, rainfall denoted M^r_τ is divided into 6 categories: 0 mm, 0 to 1 mm, 1 to 3 mm, 3 to 5 mm, 5 to 10 mm, over 10 mm - the first category given the value of 0 and the last given the value of 5 (for information regarding the distribution over time and across categories see table 4.4). Table 4.7 displays the first stages of the instrumental variable regressions for exposure via water resulting in highly predictive estimates with large F-statistics.

The presence of $\tilde{\sigma}_{i,j}$ on each side of the first stage regressions deserves additional attention. This feature of the first stage regressions contributes to the highly predictive estimates and large F-statistics and is similar to the use of lagged variables as instruments in time series or panel data. For example, if income in any period is assumed to be the product of a period specific random variable and permanent income then permanent income is included on both sides of the first stage regressions. Despite its common use, this approach has been criticized as atheoretical and biased if the error term is serially correlated - if unobserved preferences are in the error they are likely correlated with income in the current and lagged periods (Angrist

[17] Figure 4.13 displays the soil types in Metropolitan Cebu

and Krueger, 2001).

Despite some similarities, the current use of instrumental variables differs from the use of lagged variables in its theoretical basis, satisfaction of the exclusion restriction, and lack of correlation with the error term. First, because the instruments are factors of transport that directly affect an individual's exposure their selection is theoretically sound and based on mechanisms determining the regressor of interest. Second, for the majority of the transport factor instrumental variables there is no indication that they should be included in the health production function. Wind direction and speed, watershed boundaries, accumulation zones, pipe age and well depth plausibly only affect health through their impact on the quality of air and water consumed. Rain and soil type could affect health through the income of agricultural households in addition to their effects on air and water quality, a potential problem that will be analyzed through the use of stratified samples and discussed later. Finally, although distance is likely correlated with unobservables in the error term the instruments plausibly correct this correlation, isolating the variation in distance uncorrelated with the omitted variables. The capitalization of environmental quality in housing prices and preferences driving residential sorting are potential mechanisms resulting in correlation between distance and the error term. However, because housing prices likely place greater weight on proximate sources of pollution the capitalization of environmental quality in housing prices is corrected by the instruments which increase the relative weight of distant sources of pollution. Moreover, obvious, visible sources of pollution are more likely to determine residential sorting creating a correlation between distance and preferences that is corrected by the instruments that lessen the weights of obvious polluters and increase the weights of hidden polluters.

Furthermore, the endogeneity of the chosen health inputs and the socio-demographic factors in the health production function is also a legitimate concern. Community characteristics such as prices can be used to correct for the potential endogeneity of these inputs. For I_{fetal}, whether the mother consumes pre-natal vitamins, barangay level prices of grains, fruits and vegetables as well as measures of barangay health infrastructure are used as instruments with a resulting F-stat of 24.06. I_{mid}, mother's achieved education, is instrumented with the average education of mother's in the barangay and the prevalence of daycare facilities in the barangay resulting in an F-stat of 318.8. Per capita household income both at baseline and when the child is age 1 are used for A_{fetal}, A_{mid} and are instrumented with a measure of barangay electrification and water prices. The estimates result in F-stats of 31.37 and 52.95. However, whether these inputs to the health production function are instrumented or not does not change the results that will be presented in the following section and for this reason these results will not be displayed.

4.4 Results

4.4.1 Estimation Results

Examining the effects of multiple exposures to environmental toxins on height we begin with birth length. Table 4.8 shows the impact of *non-instrumented* exposures on birth length z-score. The first column only includes the measures of exposure with the other inputs in the health production function added to the second column. Moreover, the first two columns depict this relationship for all children measured at birth and the third and fourth columns show the estimates for the subsample of survey respondents that never attrit (permanently or temporarily) from the sample. In the first column we see a large and significant negative effects of exposure to carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter as well as a significant negative effect of mining emissions. Additionally, the effect of exposure to volatile organic compounds shows a significant positive impact on birth length, a result which diminishes in significance with the introduction of other inputs but remains large and positive and is likely the result of distance's endogeneity. When additional inputs are included in the estimation traffic and mining emissions demonstrate significant negative effects on birth length with mother's height and consumption of pre-natal vitamins illustrating an intuitive positive relationship. When the sample is limited to those that never attrit there are no apparent differences.

The proceeding table 4.9 is identical to table 4.8 except that the measures of exposure are instrumented. The first columns of each table so the effects of exposures alone without the additional inputs the health production function included. The results are quite different as exposure to all airborne toxins lose significance while industrial, agricultural and mining emissions via the water are significantly negative. In column two with additional inputs in the health production function included the critical exposures are shown to be traffic and mine emissions. All other exposures are close to zero or, in the case of exposure to carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter, imprecisely estimated. Again, mother's height and consumption of pre-natal vitamins are significant and positively related to birth length. These results persist for the most part when limiting the sample to individuals that never attrit, though the standard deviations of some of the estimated effects are larger because of the smaller sample size. Note also that the magnitude of the effects are reasonable in size. For instance, column 2 illustrates that the effect of a one standard deviation increase in exposure to mining water emissions decreases birth length by .156 z-scores.

An alternative way to consider the impacts of other inputs to the health production function is by estimating the interactive effects. The interactive effects provide evidence to the effectiveness of compensating behaviors. In table 4.10 instrumented exposure to the set of toxins is interacted with the binary indicator of pre-natal vitamin consumption during pregnancy.[18] The consumption of pre-natal vitamins

[18] This is done by obtaining the predicted values from the first stage and interacting them with

during pregnancy is meant to capture behaviors of the mother designed to improve the health of the child. If the consumption of pre-natal vitamins is effective in mitigating the effects of environmental toxins on birth length we will see that the non-interacted measures are more negative and the interacted measures are less negative or positive, indicating that the birth length of children born to mothers who consume pre-natal vitamins is less impacted by exposures. And this is exactly what is seen when comparing columns 1 and 2 of table 4.10. Column 1 is copied from column 2 of table 4.9 to provide comparison. The top half of column 2 shows that exposures to children whose mothers do not consume pre-natal vitamins are more negative while the bottom half of column 2 shows that mother's that consume pre-natal vitamins mitigate the risk of exposure to their unborn children. Similar results are seen for the limited sample in columns 3 and 4 of table 4.10.

In table 4.11 the effects of exposure to environmental toxins throughout life are displayed. The exposure measures presented in this table are instrumented and each column includes the results of additional inputs in the health production function. The first column is copied from column 2 of table 4.9 showing the effects of environmental toxins on birth length. Column 2 displays the effects of exposures occurring during pregnancy until age 1 on height z-score at age 1, column 3 does the same for exposures beginning in pregnancy until age 2. Column 4 displays the effects of exposures beginning in pregnancy and ending at age 2 on adult height.[19] The results are quite consistent over time. Industrial and mining emissions via water are shown to be particularly detrimental to child growth. Moreover, for the most

the binary of pre-natal vitamin consumption. When estimated the standard errors are corrected.

[19] Adult height here is measured as a z-score. This is uncommon however it is done because of attrition. The number of observations displayed under column 4 is not the number of survey respondents remaining in 2005 when most of the height observations for this outcome are obtained. Fewer than 2129 individuals remain in the sample at that time however missing values are replaced with observations collected during the 2002 wave if available. For this reason the z-score is used because each of the heights are not recorded for the same age. Table 4.17 which will be discussed later displays the results for non-z-score adult height.

part the estimated effects diminish with time indicating that there is potential for compensation and catch-up. However, early-life exposure to industrial emissions via water remain detrimental even in adulthood. However, these effects are not overly large. For adult height the coefficient on industrial water exposures is -.081 meaning that a one standard deviation increase in exposure to industrial emissions via the water during pregnancy and the first two years of life will reduce adult height by slightly under 1 cm (or approximately 1/3 inch). Also note that mother's height persists throughout life to be a positive determinant of child height and though the consumption of pre-natal vitamins contributes to very early-life height it is replaced in significance to child height with mother's education as the child ages.

For each of the aforementioned regressions in tables 8, 9 and 10 Hausman specification tests are performed to examine the difference between the instrumental variables regression and the non-instrumented regressions. In each instance the difference is shown to be significant providing evidence, though incomplete, of the instruments' necessity. One exception exists for the outcome of adult height. This is likely due to the exposures taking place long before adult height is measured and the significance of the exposures have diminished over time.

Table 4.12 repeats the regressions of table 4.11 on the limited subsample that never attrit and the results are very similar. As with the full sample industrial and mining emissions via water are the most detrimental to physical growth throughout life. Beyond the statistical significance, the magnitudes of the estimates are very similar to the full sample estimates. This similarity is a major piece of evidence that attrition, though substantial in the sample, is not driving the results. The following arguments buttress this claim. First, because this study is examining non-disaster exposures to environmental contaminants migratory responses (the main source of attrition in the sample) are less likely to occur due to environmental quality. Arguably, larger changes in environmental quality would induce greater migratory responses.

Second, because the context is a developing country with low levels of income the individual's perceived concern over environmental quality is likely dwarfed by subsistence concerns. This is similar to the assumptions involved in the environmental Kuznets curve - that at very low levels of income environmental quality is high because there are few polluters but as industrial activity and income increase environmental quality decreases until income is high enough that attention can be paid to environmental quality.[20]

Returning to the effectiveness of compensating behaviors in mitigating the negative impacts of environmental toxins, table 4.13 illustrates the impacts of behavioral responses undertaken by mothers with higher levels of education. In previous studies mother's education has been shown to affect child health because it is thought to represent the ability of the mother to understand and implement information regarding her child's health (Thomas et al., 1991). Interacting mother's education - a binary indicating the completion of high school - with measures of exposure to environmental toxins confirms previous results revealing that mother with higher education are better equipped to improve the health of their children. As with birth length and pre-natal vitamin consumption in table 4.10, the effects of exposure to children of less educated mothers are exacerbated and the effects to children of better educated mothers are mitigated.

Because the estimation of multiple, simultaneous exposures is novel it is instructive to consider what the data would reveal if the effects of each exposure was separately estimated. Table 4.14 contains the results of this exercise. The top panel in table 4.14 displays the effects of exposures on birth length while the bottom displays

[20] Additional anecdotal evidence collected from acquaintances in Metropolitan Cebu indicates that relocation is rarely driven by environmental concerns, particularly during the time period of the 1980s. First of all, these environmental concerns have only recently come to the public consciousness. Second, because of the generally low levels of income both in the survey and in Metropolitan Cebu in general, most relocations are economically driven as individuals transition through the labor force.

the effects of early-life exposures on adult height. The last column in each panel shows the results when the effects of exposure are jointly estimated for comparison. The result from separately estimating the impacts of each exposure type is that many more of them are significant - all but heavy metals and agricultural pesticides for adult height. This result is likely driven by the presence of one contaminant in the environment is correlated with with presence of others. This has both economic explanation and a chemical one. Economic activity resulting in the release of one compound into the surrounding environment is likely accompanied by other economic activities releasing additional compounds into the environment. Chemically, toxins released from sources interact with each other and other benign chemicals in the environment to produce secondary toxins. Correlation in the presence of environmental toxins has recently been shown in other studies such as Greenstone and Hanna (2011) and Barrett et al. (2010).

As previously mentioned, height is a marker of both health and human capital, particularly in developing countries such as the Philippines (Foster and Rosenzweig, 1993; Haddad and Bouis, 1991). The demonstrated effects of multiple exposures on height can therefore be interpreted as also effects to human capital. However, in order to more strictly examine the effects to human capital the following table will display the estimated effects of early-life exposure to environmental toxins on two types of cognitive tests during early adolescence as well as labor market outcomes in adulthood. The first outcome considered is a non-verbal intelligence test score with possible values ranging from 0 to 100. This test was administered to each non-attriting child in the Cebu Longitudinal Health and Nutrition Survey during the 1994 wave when the children were approximately 10 to 11 years old. The first column of table 4.15 displays these results. Again the impact of a one standard deviation increase in exposure to industrial emissions via water lowers the test score by 1.3 points. The average test score as seen in table 4.1 is 65 points. The next test is a math test again administered to each child in the 1994 wave of the CLHNS. The scores on this test originally ranged from 0 to 60 however were corrected to range from -20 to 60. The average test score as described in the summary statistics of table 4.1 is 16.65. Again, industrial emissions via water are shown to lower this test score by 1.7 points with a 1 standard deviation increase in exposure. Additionally, heavy metals exhibit a large and significant negative effect: -2.7. Another metric of human capital that is examined are labor market outcomes the survey respondents experienced in 2005. In 2005 the children of the CLHNS were approximately 22-23 years old and many of them had entered the labor market and were earning an average hourly wage of 31 pesos.[21] Consistent with the non-verbal and math tests as well as the results for height industrial emissions via water exhibit a significant negative effect on hourly earnings. The observed effect, a reduction of 5 pesos per hour is not without some caveats. First, as shown in the table the number of observations in this regression is small and as a result many of the coefficients are imprecisely estimated. Furthermore, no correction has been made for selection into the labor market. With these caveats in mind, the effects of early-life exposure to environmental toxins on hourly earnings in adulthood corroborate the non-verbal and math test scores as well as the previously discussed results for height.

Another important point to mention from table 4.15 is that exposure to biological contaminants exhibits a large negative effect on test scores. The measure of biological contamination is an interviewer recorded score of the sanitary conditions in and around the survey respondent's residence. This is interesting because previous studies in toxicology and epidemiology have shown that the interactive effects of exposures to biological contaminants and environmental toxins such as heavy metals produce

[21] In 2005 this equated to roughly 60 US cents. Clearly this is quite low however because the earnings information includes individuals that only work in home production or that only work occasionally and report monthly or yearly earnings the average hourly earning is pulled towards zero. The maximum value of hourly earnings is 830 pesos, which in 2005 equated to 15 dollars an hour.

detrimental effects to human capital development (Roy et al., 2011). Table 4.15 hints to these same results and in table 4.16 the measures of exposure to environmental toxins are interacted with an indicator of unsanitary conditions in and around the respondent's home. The results displayed in table 4.16 confirm the epidemiological evidence that interactive effects of exposures to both chemical environmental toxins and biological contaminants are detrimental to human capital. The unexposed to biological contaminants exhibit less negative effects due to industrial emissions via water. And the effect for those that are exposed to both is very large and negative in the case of non-verbal intelligence. Consistent across the tests are the large negative impacts of exposure to biological contaminants in interaction with both heavy metals and carbon monoxide and other particulates. The caveat here is that residing in an unsanitary environment is likely correlated with other determinants of health and no instruments are available to correct this likely correlation.

Table 4.17 concludes the empirical results by showing the estimated effects of fetal and early-life exposures to environmental toxins on additional health outcomes such as birthweight, acute respiratory illness, non-z-score height, stunting and BMI. Before discussing further, note that for the binary outcomes in this table (low birthweight and stunting) the estimations are standard OLS making them linear probability models. For low birthweight, the results are similar to the the results for birth length in that mining emissions are detrimental. A one standard deviation increase in exposure to mining emissions increases the likelihood of low birthweight by approximately 3%. Industrial emissions are also marginally significant and traffic emissions are not significant, as opposed to their significant effects on birth length. Surprisingly, given the large number of studies linking low birthweight to carbon monoxide or particular matter exposures, the proxy measure of carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter exposure is not statistically significant though the estimate is negative. In column 2 the outcome is acute respiratory illness, the total number of incidences during the child's first two years of life they experienced a respiratory attack and were brought to the hospital or treated at home (as recalled by the mother). A large number of studies link carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter exposures as well as heavy metal exposures to acute respiratory illness. No study (of which the author is aware) links volatile organic compounds to acute respiratory illness and water borne emissions are not likely to results in acute respiratory illness. The results show that both the proxy measure of carbon monoxide, nitrogen oxides, sulfur oxides and particulate matter exposure and the measure of heavy metal exposure increase the number of acute respiratory incidences while VOCs and waterborne exposures decrease or do not affect the number of incidences. This result provides strong evidence that the proxy measures for each type of environmental contaminant are measuring what they purport to measure. The following three columns report the effects of exposures on a non-z-score adult height, a binary indicator of adult stunting (below 2 standard deviations of age specific median height), and adult BMI. The results are consistent with the adult height z-score results.

4.4.2 Discussion

A potential problem for the instrumental variable strategy is that instruments do not satisfy the exclusion restriction. Wind, piped network and others do not likely affect health except through the transport of toxins, but rain and soil type could affect health through the income of agricultural households in addition to their effects on air and water quality. To examine the potential bias introduced by the use of rain and soil type instruments the sample is stratified and the impacts of exposure estimated for non-agricultural households only. Appendix table A.17, the first table in the appendix for this chapter, compares the full sample to the non-agricultural household sample estimates of exposure's impact on birth length and adult height.

Overall, the results for the non-agricultural household sub-sample are very similar to the full sample results, with only minor differences in the magnitudes. This provides evidence that the rain and soil type instruments satisfy the exclusion restriction. Moreover, any bias is likely to be small because less than 10% of the sample reports cultivating at least one parcel of land.

If the exclusion restriction is satisfied, it is critical to examine whether the instruments are isolating the variation in the distance proxy of exposure unrelated to the omitted determinants of health. First, consider one potential source of bias that arises if environmental quality is capitalized into housing prices resulting in the non-random geographic distribution of households with the capacity to improve their child's health. Intuitively, the instruments correct for this by placing greater relative weight on more distant sources of pollution unlikely to be capitalized in housing prices. However, referring again to columns 2 and 4 of tables 7 and 8, notice that the instrumented and non-instrumented effects of exposure are very similar. In fact, the only difference is that the magnitudes of the effects of exposure to traffic and mining emissions marginally increase when instrumented. The similarity of the instrumented and non-instrumented coefficients suggests that if the instrumental variables are effective the bias resulting from the potential capitalization of environmental quality in housing prices is small. Corroboration is provided from the geographic distribution of reported housing values. Appendix figure A.1 displays the map of Metropolitan Cebu with the pollution sources and sample barangays highlighted. The colors of the highlighted sample barangays vary by the average reported monthly rent of the household. If environmental quality were capitalized in housing prices the most expensive housing would be found at greater distances from the sources of pollution but in the context of Metropolitan Cebu the opposite is true. Perhaps unsurprisingly in a developing country context lower on the income dimension of the environmental Kuznets curve and unaware of the threats of pollution to health, the most expensive housing is concentrated in urban areas close to polluters.

Now consider another potential source of bias that the instrumental variable strategy aims to correct the correlation between residential sorting and preferences. Different from the capacity to improve health, if residential sorting is correlated with parental preferences for child health the estimated effects of the distance proxy of exposure will be biased. The instrumental variable strategy is designed to correct this bias by reducing the weight of visible, obvious polluters relative to distant, hidden polluters. However, it is possible that individuals interpret the factors of transport to determine and avoid exposure to hidden polluters. The factors dictating the transport of environmental toxins via water are unavailable to individuals without unique access to information on the piped water network and topography dictating groundwater flow so the opportunity for individuals to avoid exposures from hidden polluters transported via water are minimal. Factors of transport by air and much more available so the potential for individuals to avoid exposure via air to distant, hidden polluters is much greater. However, evidence suggests that avoidance measures undertaken by survey respondents is minimal. A potential avoidance measure that parents can undertake is fertility planning. In the context of Metropolitan Cebu, the Amihan and Habagat seasons dominate wind patterns - the Amihan season from October to April is dominated by a northeastern wind and the Habagat is dominated by a southwestern wind. If fertility planning related to environmental exposures is occurring distinct geographic patterns of birth would arise to avoid downwind from polluters during pregnancy. However, appendix figure A.2 shows that pregnancies more likely to end during the Habagat (May-September) are distributed throughout Metropolitan Cebu without any pattern indicating fertility planning related to environmental exposures. Moreover, the small differences between the instrumented and non-instrumented estimates in tables 7 and 8 suggest that the correlation between residential sorting and preferences is not large.

Sample selection and attrition are the final potential sources of bias that will be discussed. The sampling of the CLHNS data began by surveying all households in 1982 of the 33 randomly selected barangay to identify women that would give birth between May 1, 1983 and April 30, 1984. After the survey, community informants were hired to inform the survey team of newly pregnant women. After being identified, the baseline survey of pregnant mothers took place when the mothers were 6-7 months pregnant. A potential risk for this sampling strategy is that women who are unaware they are pregnant or give birth later during the one-year period are excluded from the sample. The distribution of the sample by birth month shows that for each month from January 1984 and April 1984 less than 7% of the sample children are born, contrasting with the preceding months of 1983 in which 8 to 10% of the sample is born. If the geographic distribution of this sampling selection results in an oversampling of children living close to pollution sources the resulting bias could produce the results previously discussed. However, as seen in figure A.3 there is no particular geographic pattern to the distribution of pregnancies more likely to end between January and April 1984. Regarding attrition, appendix table A.18, the second table in the appendix for this chapter, shows the regressions of instrumented and non-instrumented exposure on three definitions of attrition. The outcome of the first two columns is a binary indicator of temporary attrition, that the individual disappears from the sample for at least one wave. The third and fourth columns use the binary indicator of permanent attrition and the fifth and sixth columns use a binary indicator equal to one is the individual ever temporarily or permanently attrited. In general the non-instrumented distance measures of exposure are better at predicting attrition. Additionally, the instrumented mining and industrial water emissions measures of exposure which are consistently significant, negative determinants of health and human capital do not predict attrition. These results are suggestive that attrition is not driving the results of the study but the previous tables showing essentially no difference between the estimated effects using the full sample versus those of the non-attritor sample are the most convincing.

4.5 Conclusion

By examining multiple types of environmental contamination in the developing country context of Metropolitan Cebu, Philippines insights regarding environmental determinants of health are gained. Exploiting the Cebu Longitudinal Health and Nutrition Survey that has taken place since 1983 in Metropolitan Cebu, Philippines as well as unique geographic data, such as the location of industrial polluters, mines and agriculture as well as existing piped water networks exposures to environmental contaminants are analyzed for their effects on height, a measure of both health and human capital in this context. A health production function is developed and used to frame the analysis of environmental and other inputs affecting health. Distances from polluters proxy for contamination levels and are instrumented to correct for likely correlation with unobserved determinants of health by detailed topographic, meteorologic and local infrastructure factors driving the transport of the contaminant from the source to the individual. These geographic factors of transport provide spatial and temporal variation exogenous to residential sorting. The longitudinal characteristic of the survey enables the analysis of both short and long-term effects of exposure to environmental toxins during pregnancy and the first two years of life. This study also pays particular attention to compensating behaviors and demonstrates that compensating investments such as the consumption of pre-natal vitamins can mitigate the negative impacts of exposures to environmental toxins. In summary, the results illustrate the negative effects to health measured by height of exposure to multiple types of environmental contaminants, particularly industrial and mining emissions carried by water. The magnitude of the effects of exposure during early-life diminish with age though, in the case of industrial emissions, they remain significant in adulthood. The consumption of pre-natal vitamins, capturing behaviors related to improving the child's health, is shown to be consistently positively related to height, as is the education of the mother which captures the ability of the mother to assimilate and incorporate information regarding the child's health. Each of these markers of compensating behaviors are shown to mitigate the effects of environmental toxins. Moreover the results demonstrate the because exposures to environmental toxins are likely correlated when their impacts are separately estimated they can be misattributed. Furthermore, the combined exposure to both biological and non-biological contaminants negatively impacts human capital and attrition does not appear to be driving the results.

4.6 Figures

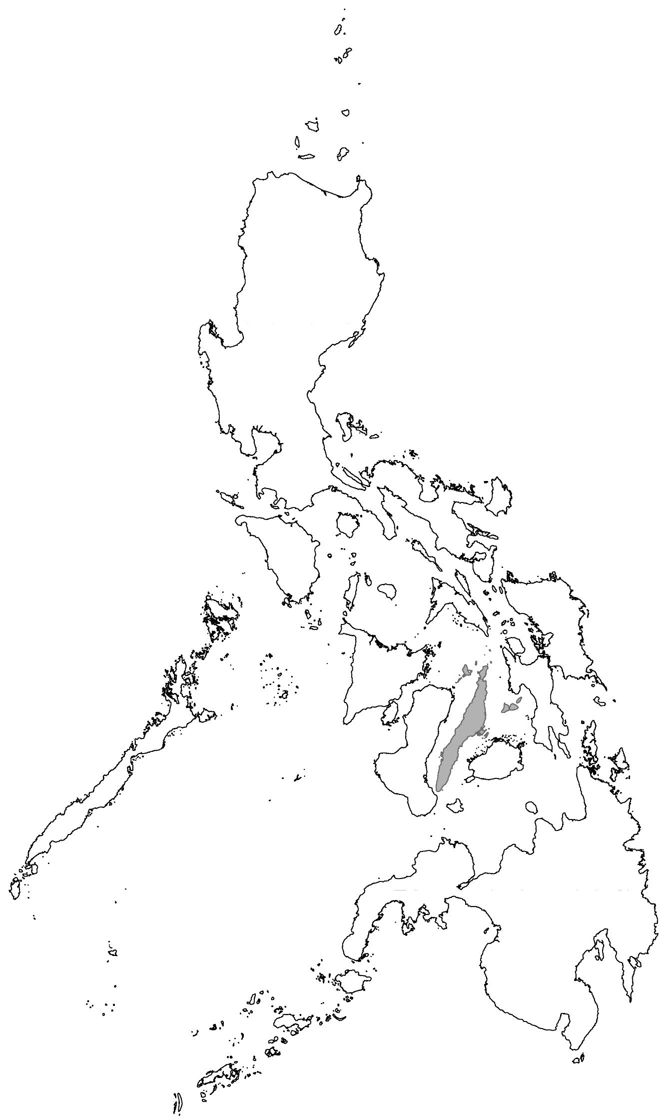

Figure 4.1: Map of the Philippines with Cebu Province highlighted

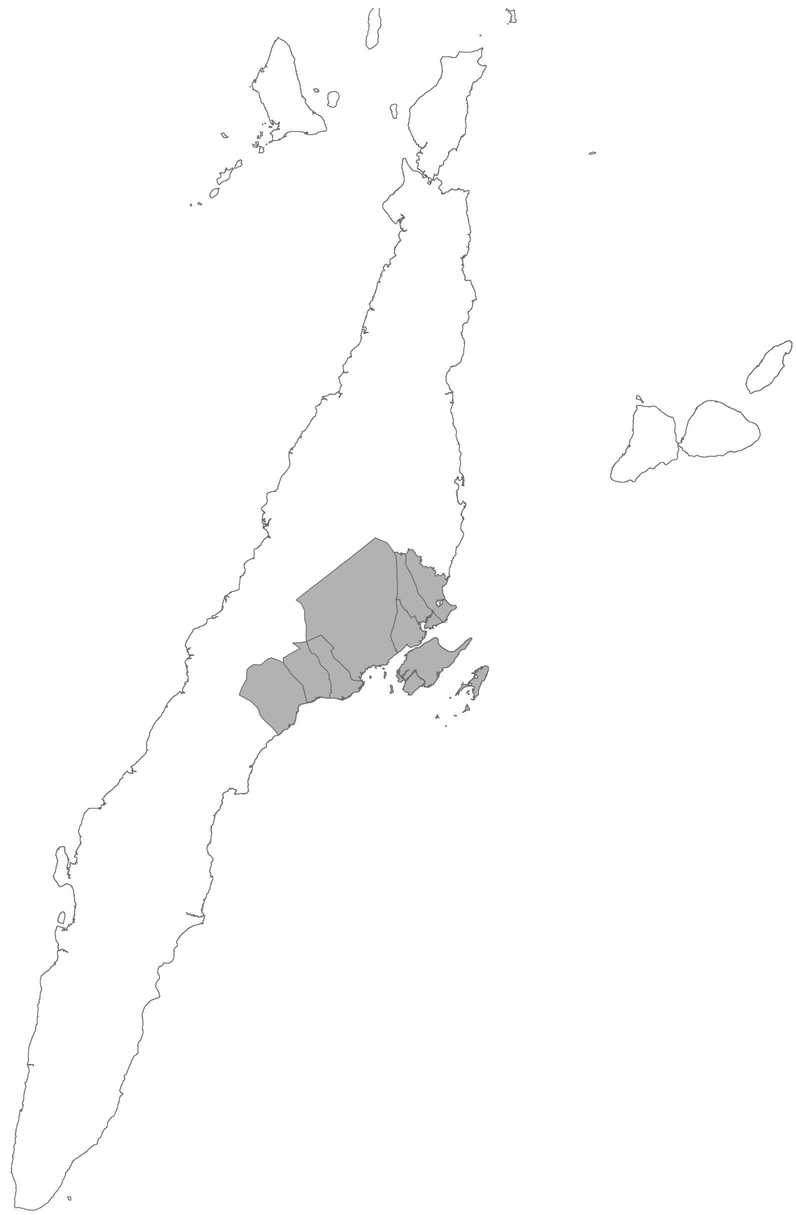

Figure 4.2: Map of Cebu Province with Metropolitan Cebu highlighted

Figure 4.3: Map of the Cities and Municipalities of Metropolitan Cebu

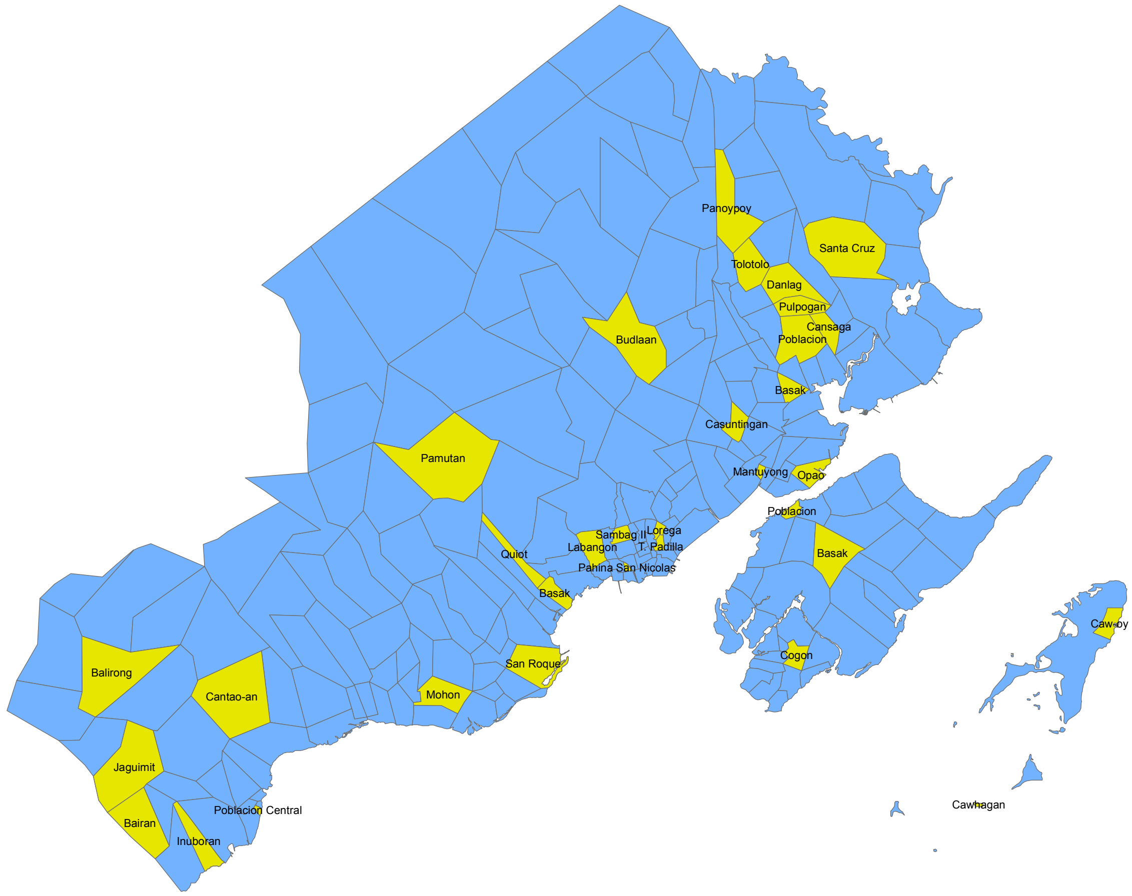

FIGURE 4.4: Map of barangays and sample barangays selected for the CLHNS study

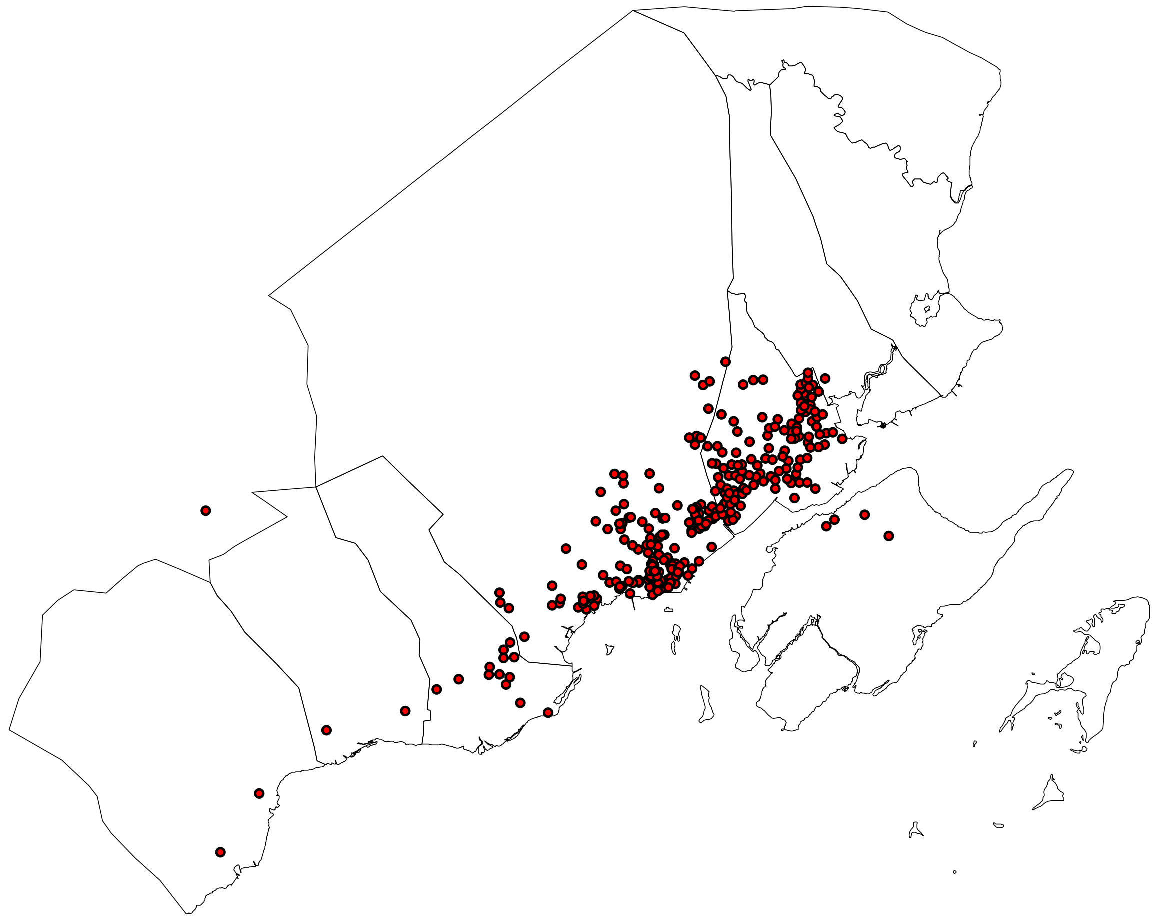

FIGURE 4.5: Map of industrial polluters in Metropolitan Cebu

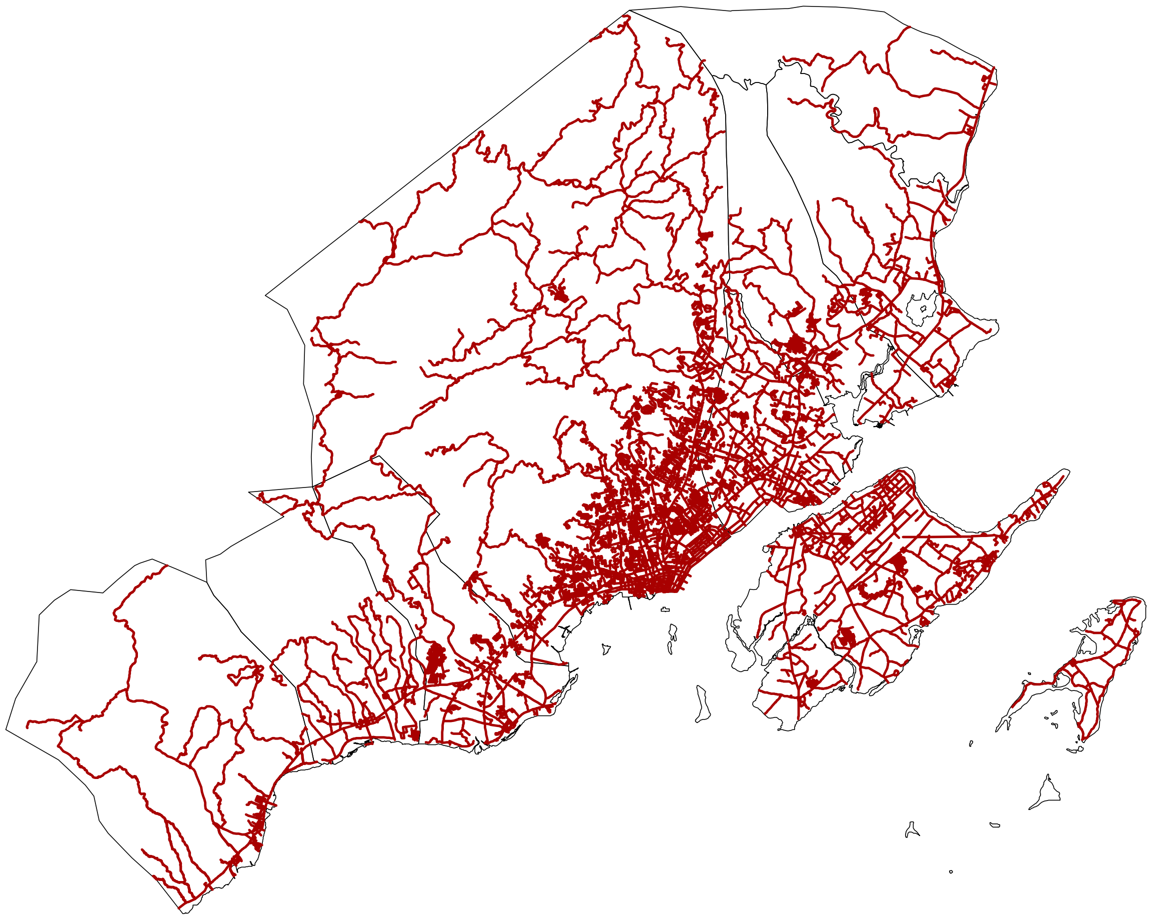

Figure 4.6: Map of Roads in Metropolitan Cebu

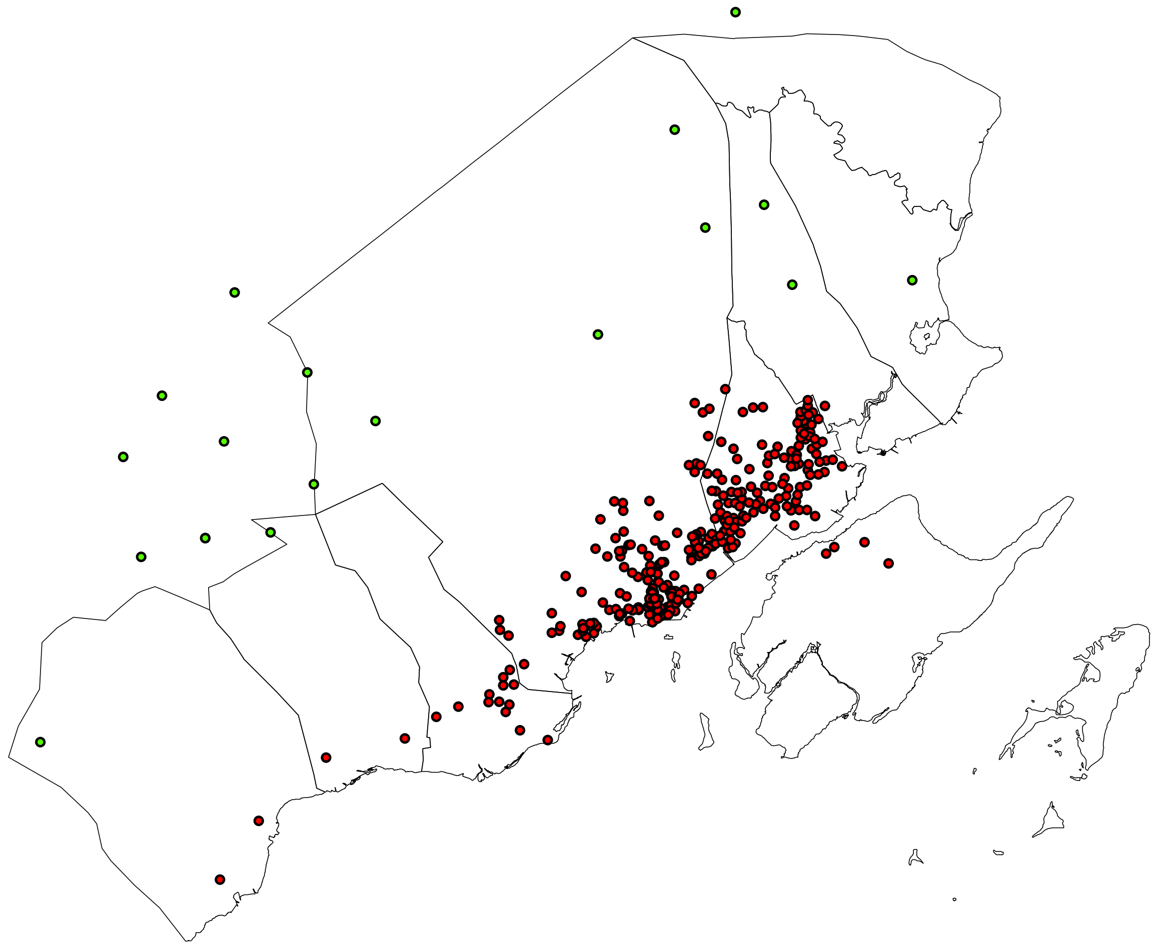

Figure 4.7: Map of industrial polluters and mines in Metropolitan Cebu

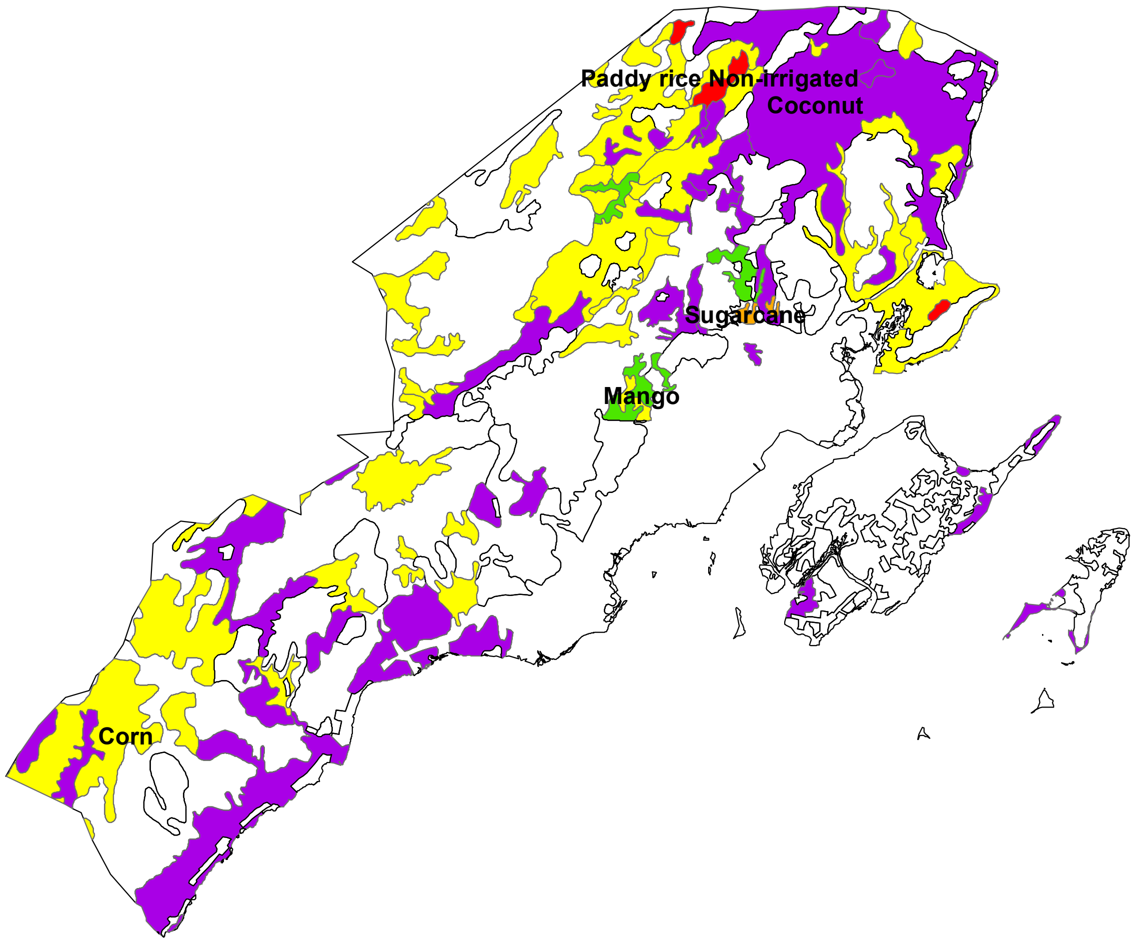

Figure 4.8: Map of Land Use in Metropolitan Cebu

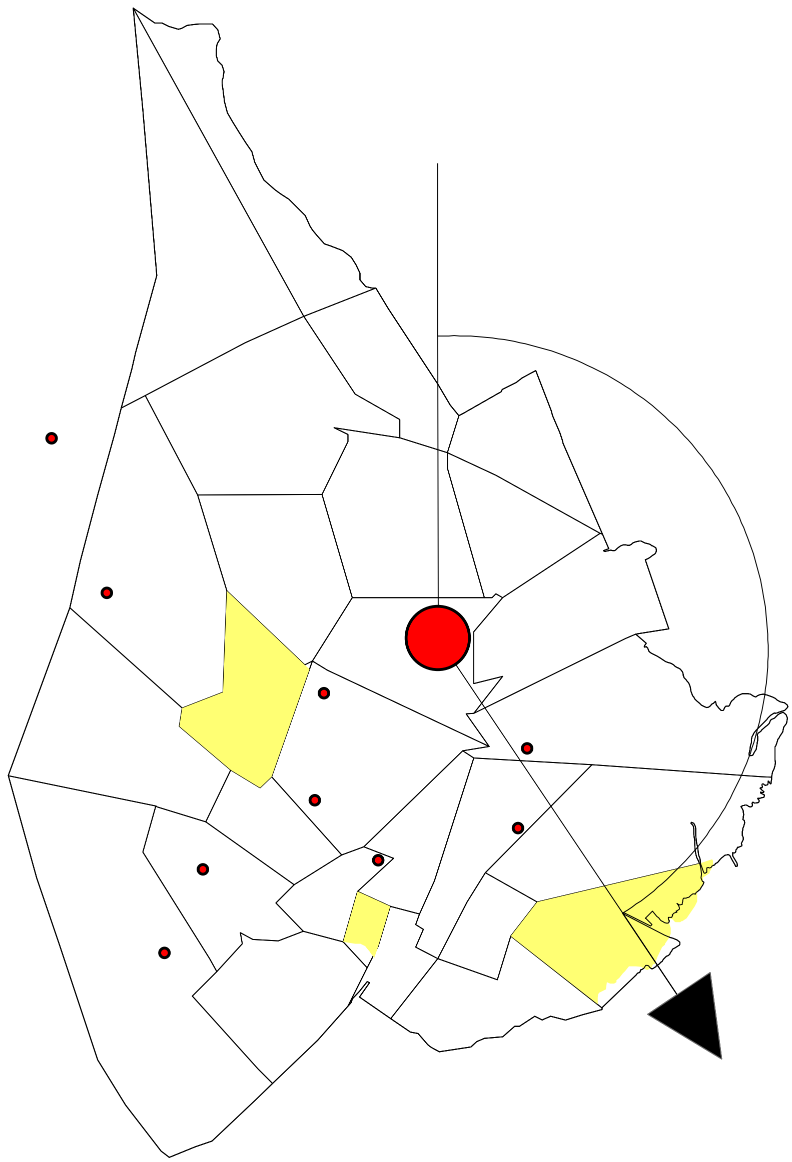

FIGURE 4.9: Map of Mandaue Barangays, Polluters and Wind Direction

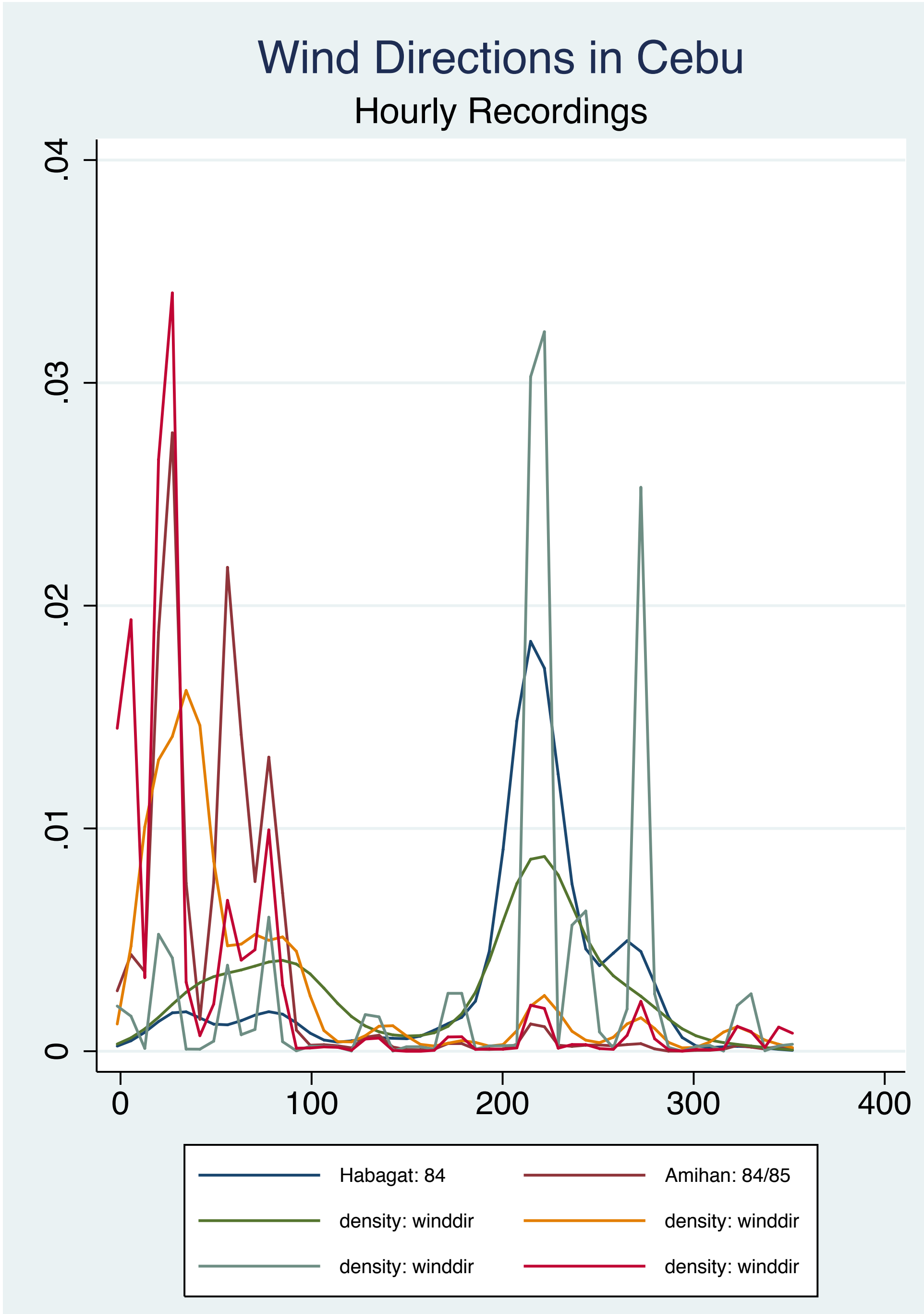

FIGURE 4.10: Kernel density of wind directions for multiple Amihan and Habagat seasons

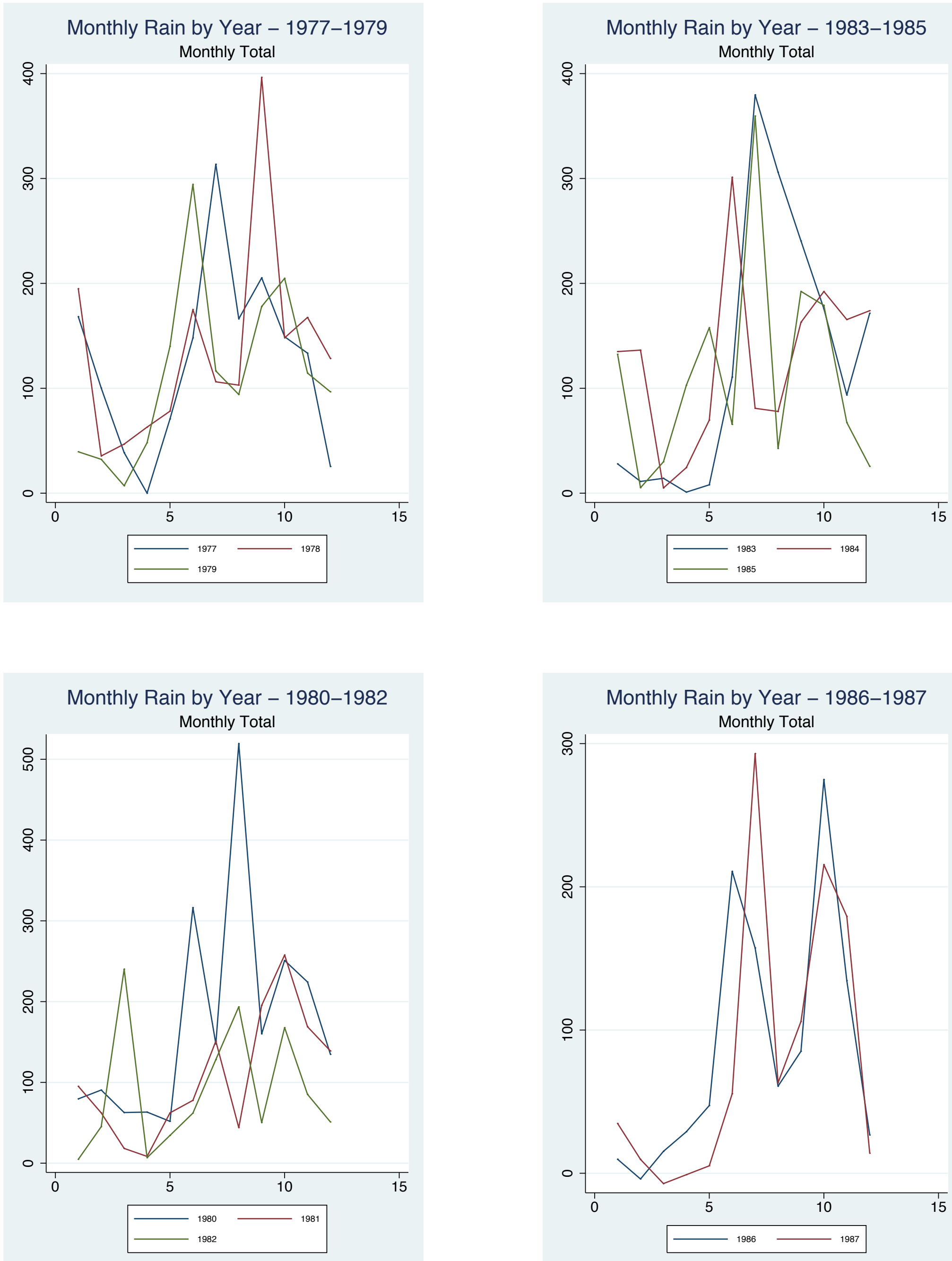

FIGURE 4.11: Monthly rainfall for multiple years

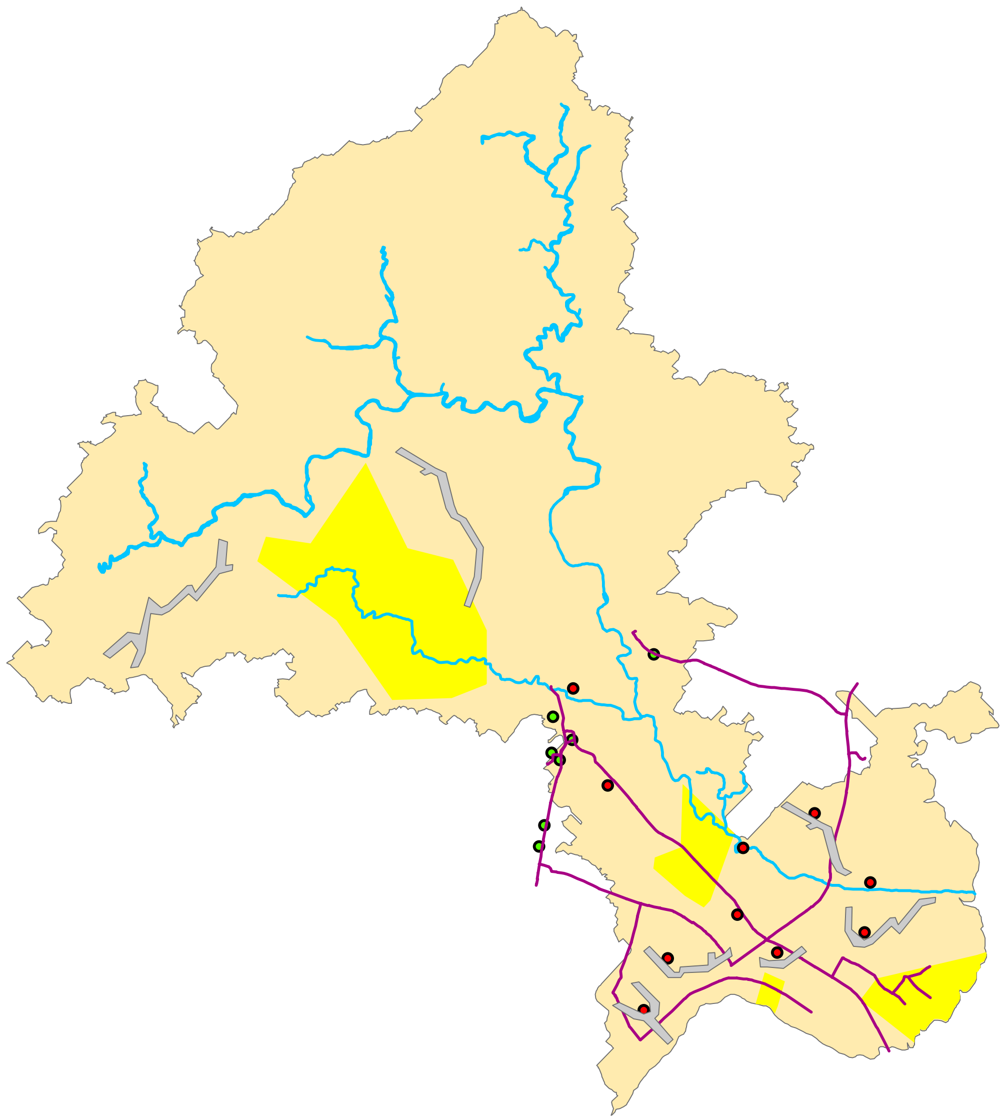

Figure 4.12: Map of Mandaue Watershed with Topography and Infrastructure and Polluters

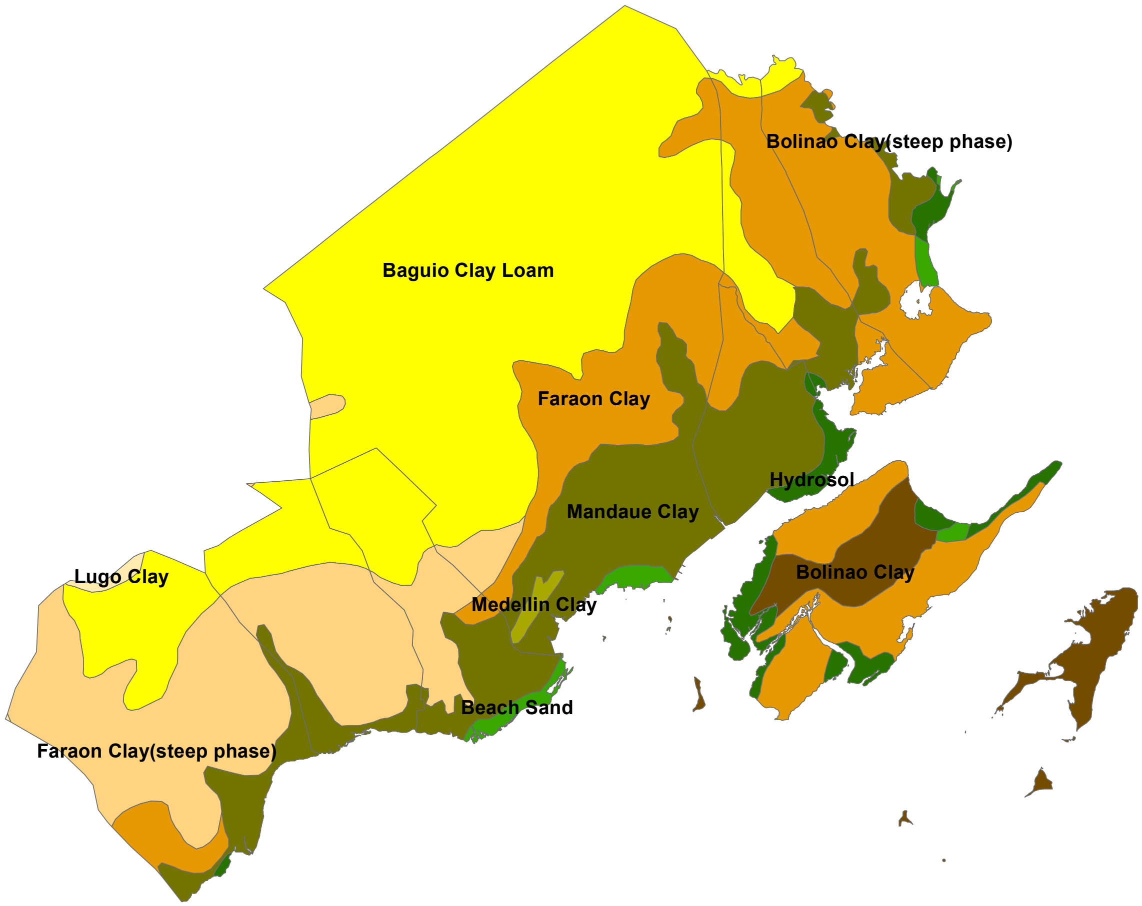

FIGURE 4.13: Map of Soil Types in Metropolitan Cebu

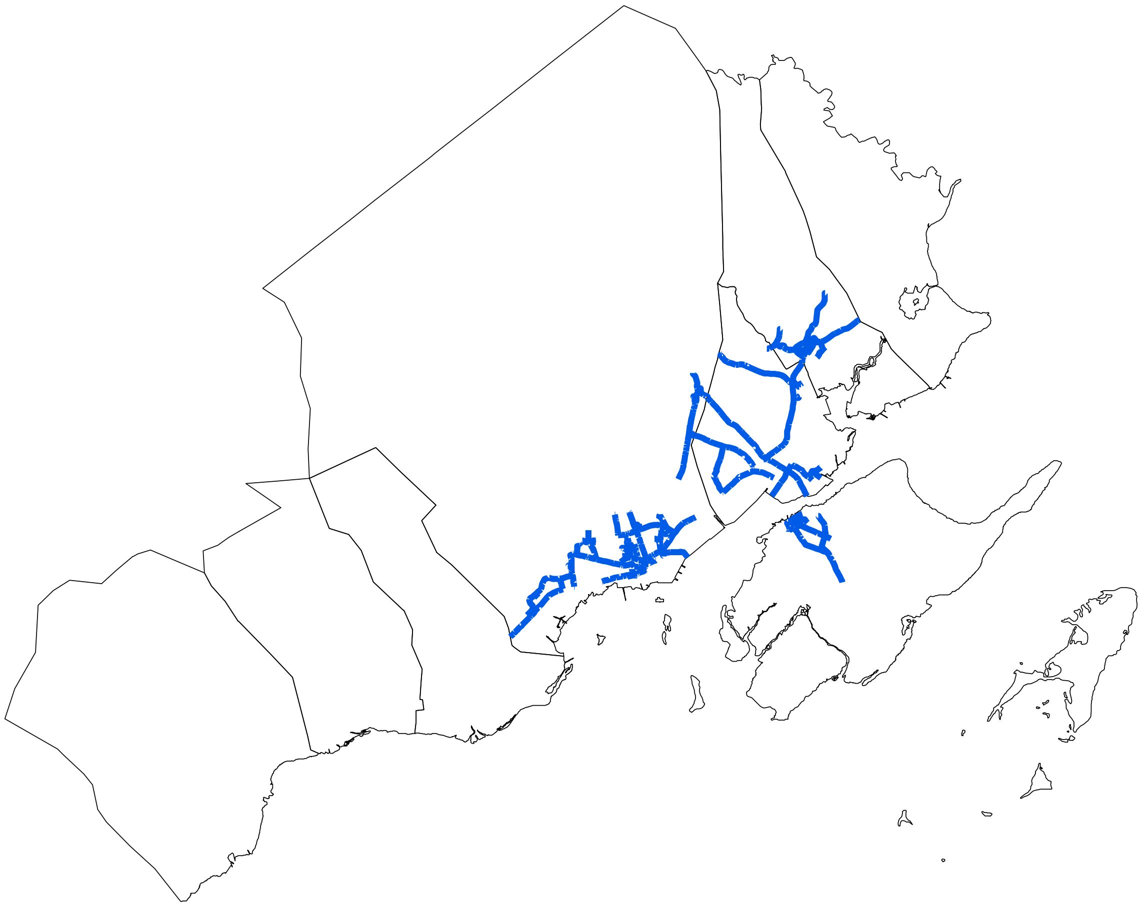

Figure 4.14: Map of MCWD 1986 Pipe Sections in Metropolitan Cebu

4.7 Tables

Table 4.1:

Summary Statistics of Survey Respondents

	Percent or Mean	Std. Dev.
Mother Statistics (n=3327)		
Elementary school or less education %	54	
Smoked during pregnancy %	14	
Drank alcohol during pregnancy %	8	
Consumes pre-natal vitamines %	58	
Number of previous live pregnancies	2.23	2.2
Number of previous non-live pregnancies	0.29	0.63
Height in cm	150.64	5.1
Age in years	26.04	5.98
Father Statistics (n=3327)		
Father present in household %	94	
Elementary school or less education %	47	
Age in years	28.82	6.56
Child Health at Birth (n=3122)		
Male %	53	
Stillbirth/miscarriage/died within 7 days %	2	
Died within first year %	4	
Low birth weight (<2500 grams) %	12	
Birth weight in kg	3.01	0.48
Birth length in cm	49.25	2.14
Child Health in Adulthood (n=2129)		
Elevated C-reactive protein %	11	
Height in cm	157.16	8.8
Weight in kg	51.32	10.04
Body Mass Index	20.71	3.29
Child Human Capital at Age 10 and in Adulthood		
Non-verbal IQ test score in 1994 (0 to 100)	65.13	15.3
Math test score in 1994 10 (corrected -20 to 60)	16.65	13.12
Hourly earnings (pesos) in 2005	30.74	45.88
Water Use at Baseline (n=3327)		
Piped water (MCWD) %	40	
Well, spring, river or rain %	59	
Bottled water %	1	
Minutes to walk to source	3.01	4.95
Income in Philippine Pesos (n=3327)		
Per capita household monthly income at baseline	255.37	309.62
Per capita household monthly income child age 1	266.18	328.8
Per capita household monthly income child age 2	315.02	534.04
Per capita household monthly income when child is adult	2799.43	3334.96
Migration and Attrition (n=3327)		
During 1983-86 migrate from urban to rural area %	2	
During 1983-86 migrate from rural to urban area %	1	
During 1983-86 migrate to/from same area classification %	17	
Ever temporarily attrit throughout all waves %	17	
Ever permanently attrit throughout all waves %	24	

Table 4.2:

Respondent Residence by City and Barangay		
	Percent	**N**
Cebu City	46.8	1461
Quiot Pardo	4.2	131
San Nicolas	2.95	92
Sambag II	6.98	218
Basak Pardo	4.97	155
T. Padilla	5.58	174
Labangon	10.77	336
Lorega San Miguel	7.75	242
Budla-an	1.89	59
Pamutan	1.73	54
Consolacion	11.76	367
Cansaga	0.54	17
Poblacion	3.43	107
Danlag	0.8	25
Panoypoy	0.54	17
Pulpogan	5.35	1.67
Tolo-tolo	1.09	34
Cordova	1.44	45
Cogon	1.44	45
Lapu-Lapu	9.43	2.94
Basak	5.51	172
Poblacion	2.85	89
Cao-oy	0.67	21
Caohagan	0.38	12
Lilo-an	0.9	28
Santa Cruz	0.9	28
Mandaue	13.81	431
Opao	3.97	124
Mantuyong	3.4	106
Basak	2.92	91
Casuntingan	3.52	110
Naga	8.81	275
Jaguimit	1.22	38
Balirong	2.24	70
Bairan	0.83	26
Cantao-an	2.18	68
Inoburan	1.86	58
Poblacion	0.48	15
Talisay	7.05	220
San Roque	4.42	138
Mojon	2.63	82
Urban Population	76.4	2384

Table 4.3:

Sources of Environmental Contamination

	N
CO, NOx, SOx, and PM10:	**150**
Metal Manufacturing	40
Food and Beverage	82
Concrete, Cement and Construction Goods	26
Airport	1
Large, Open Copper Mine	1
Major Sources:	**17**
Volatile Organic Compounds:	**149**
Pharmaceutical Manfacturing	11
Chemicals and Fertilizers Manufacturing	36
Furniture Manufacturing	82
Plastic and Rubber Manufacturing	20
Major Sources:	**16**
Heavy Metals:	**25**
Glass Manufacturing	22
Gold Mine	1
Coal Fired Power Plant	2
Major Sources:	**2**
Industrial Water Emitters:	**67**
Pharmaceutical Manfacturing	11
Chemicals and Fertilizers Manufacturing	36
Plastic and Rubber Manufacturing	20
Major Sources:	**8**
Mining Water Emitters:	**22**
Clay	2
Coal	5
Copper	13
Gold	1
Silver	1
Major Sources:	**1**

Notes: Locations and industry information is obtained mainly from DPC records in combination with Cebu City and EMB records.

Table 4.4:

Wind Direction, Wind Speed and Rain - Percent of Annual Observations

	1978	**1979**	**1980**	**1981**	**1982**	**1983**	**1984**	**1985**	**1986**
Wind Direction									
Northeast (10-90 degrees)	37.0	33.1	42.5	42.8	39.2	45.8	38.5	35.1	39.5
Southeast (100-180 degrees)	5.6	4.1	4.2	3.1	5.5	2.5	3.0	4.2	2.5
Southwest (190-270 degrees)	19.6	29.1	18.4	15.7	14.1	10.6	17.5	17.4	19.9
Northwest (280-360 degrees)	19.7	31.0	18.5	11.8	19.4	3.7	5.5	4.1	2.9
Wind Speed (kilometers per hour)									
0 kph	27.3	30.4	39.4	25.0	8.5	37.1	35.4	39.1	34.9
1 to 3 kph	20.7	25.3	29.3	33.8	26.5	23.4	28.8	23.4	17.1
3 to 5 kph	27.3	29.1	24.1	29.9	39.3	24.6	22.3	25.6	26.4
5 to 10 kph	24.4	14.6	6.8	10.1	25.2	14.5	13.3	11.6	21.1
Over 10 kph	0.2	0.2	0.1	0.6	0.0	0.0	0.1	0.1	0.3
Precipitation (millimeters)									
0 mm	45.8	39.5	37.4	43.3	40.8	44.9	30.1	41.1	37.5
0 to 1 mm	15.9	19.5	18.3	21.9	19.5	12.3	16.9	14.5	18.6
1 to 3 mm	9.6	12.3	10.1	12.1	18.4	11.5	17.8	14.8	14.2
3 to 5 mm	5.2	5.8	6.6	5.8	5.5	5.8	8.2	5.5	7.7
5 to 10 mm	9.3	10.4	8.7	7.7	8.0	10.7	9.6	8.0	9.6
Over 10 mm	14.2	12.6	18.9	9.3	8.0	14.8	17.5	16.2	12.3

Notes: Hourly observations of wind direction and speed are obtained from the NCDC. Rainfall is obtained from the WRC.

Table 4.5:

Pipe Age, Pipe Length, Well Depth and Soil Flow Index by City

	Naga	**Talisay**	**Cebu City**	**Mandaue**	**Lapu-Lapu**	**Cordova and Islands**	**Consolacion and Liloan**
Age in Years of Pipes Serving City							
Mean	None	None	8.42	7.53	8.10	None	7.80
Standard Deviation			2.40	0.98	0.00		0.61
Minimum			4.27	5.57	8.10		5.52
Maximum			12.77	9.24	8.10		8.20
Length of Pipes in City (by 1986)							
Meters	None	None	40012	24797	9642	None	11330
Soil Flow Index (0-2) of Contributing Watershed(s)							
Mean	0.72	0.95	1.02	0.68	1	1	0.81
Standard Deviation	0.37	0.62	0.30	0.43	0	0	0.25
Minimum	0.19	0.12	0.12	0.39	0	0	0.34
Maximum	2	1.41	1.59	1.37	1	1	1.26
Use of Deep Wells							
Percent of City Residents	23	87	72	90	10	15	76

Notes: The soil flow index is derived from Huddleston (1996) using PPDO maps, pipe age from MCWD records, well depth from CLHNS survey responses and rainfall from the WRC.

Table 4.6:

IV First Stage: Air Pollution

	Distance			
	CO, NOx, SOx, PM10	**Volatile Organic Compounds**	**Heavy Metals**	**Traffic Emissions**
Wind Direction				
CO, NOx, SOx, PM10	1.015***			
	(0.024)			
Volatile Organic Compounds		1.083***		
		(0.025)		
Heavy Metals			0.050	
			(0.034)	
Traffic Emissions				1.210***
				(0.017)
Wind Direction and Speed				
CO, NOx, SOx, PM10	-0.584***			
	(0.035)			
Volatile Organic Compounds		-0.422***		
		(0.038)		
Heavy Metals			-0.200***	
			(0.050)	
Traffic Emissions				-0.703***
				(0.028)
Wind Direction, Speed and Rainfall				
CO, NOx, SOx, PM10	0.342***			
	(0.023)			
Volatile Organic Compounds		0.101***		
		(0.024)		
Heavy Metals			-0.047	
			(0.034)	
Traffic Emissions				0.204***
				(0.021)
Observations:	3,122	3,122	3,122	3,122
R-squared:	0.512	0.629	0.041	0.712
F statistic:	1,090.844	1,762.400	44.789	2,567.117

Notes: The sum of the inverse distances from the center of the survey respondent's barangay to each pollution source of a particular type is used to proxy for exposure. Wind direction is the percent of time spent downwind from each source and is obtained, as is wind speed, from the NCDC. Rainfall is obtained from the WRC. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.7:

IV First Stage: Water Pollution

	Distance		
	Industrial Emissions	**Agricultural Pesticides**	**Mining Emissions**
Soil Flow Index and Watershed Binary			
Industrial Water Emissions	0.870***		
	(0.040)		
Agricultural Pesticides		1.003***	
		(0.030)	
Mining Emissions			0.843***
			(0.011)
Soil, Watershed and Pipe Age/Well Depth			
Industrial Water Emissions	-0.013		
	(0.040)		
Agricultural Pesticides		-0.092***	
		(0.030)	
Mining Emissions			0.130***
			(0.011)
Soil, Watershed, Pipe/Well and Rainfall			
Industrial Water Emissions	-0.007		
	(0.012)		
Agricultural Pesticides		0.006	
		(0.008)	
Mining Emissions			-0.008
			(0.006)
Observations:	3,327	3,327	3,327
R-squared:	0.728	0.841	0.914
F statistic:	2,961.281	5,847.374	11,783.407

Notes: The sum of the inverse distances from the center of the survey respondent's barangay to each pollution source of a particular type is used to proxy for exposure. The soil flow index is derived from Huddleston (1996), pipe age from MCWD records, well depth from CLHNS survey responses and rainfall from the WRC. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.8:

Health Production Function: Birth Length
Non-Instrumented Exposures

	All Live Births: Birth Length Z-Scores		Subsample that never attrits: Birth Length Z-Score	
	Only Exposure	**Health Prod. Function**	**Only Exposure**	**Health Prod. Function**
Fetal Exposures:				
CO, NOx, SOx, PM10	-0.309***	-0.112	-0.307**	-0.107
	(0.105)	(0.149)	(0.145)	(0.170)
Volatile Organic Compounds	0.428***	0.236	0.408**	0.232
	(0.147)	(0.170)	(0.182)	(0.209)
Heavy Metals	-0.030	0.024	-0.030	0.029
	(0.057)	(0.054)	(0.053)	(0.055)
Traffic Emissions	-0.109	-0.176**	-0.110	-0.187**
	(0.072)	(0.073)	(0.070)	(0.077)
Industrial Water Emissions	-0.027	-0.025	-0.037	-0.046
	(0.027)	(0.030)	(0.032)	(0.034)
Agricultural Pesticides	0.007	0.016	-0.024	-0.007
	(0.020)	(0.019)	(0.022)	(0.022)
Mining Water Emissions	-0.087***	-0.096***	-0.088***	-0.097***
	(0.023)	(0.016)	(0.025)	(0.018)
Other Inputs:				
Mother's Height		0.016***		0.012
		(0.005)		(0.007)
Mother's Age		0.007**		0.006
		(0.003)		(0.005)
Father's Age		-0.001		-0.003
		(0.003)		(0.005)
Disease Environment during Pregnancy		-0.151		-0.192
		(0.120)		(0.135)
Mother consumes pre-natal vitamins		0.136***		0.090**
		(0.037)		(0.041)
Per Capita Household Income during Pregnancy		0.000*		0.000
		(0.000)		(0.000)
Observations (N):	3059	3059	1884	1884

Notes: This table shows the impact of exposures on birth length for the entire sample of live-births with recorded lengths in columns 1 and 2, and for the subsample that never temporarily or permanently attrits. Column 1 estimates the impact of exposures alone while column 2 includes additional parental inputs affecting health (similarly for columns 3 and 4). Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.9:

Health Production Function: Birth Length
Instrumented Exposure

	All Live Births: Birth Length Z-Scores		Subsample that never attrits: Birth Length Z-Score	
	Only Exposure	**Health Prod. Function**	**Only Exposure**	**Health Prod. Function**
Fetal Exposures:				
CO, NOx, SOx, PM10	0.464	0.102	0.524	0.236
	(0.285)	(0.245)	(0.374)	(0.287)
Volatile Organic Compounds	-0.290	-0.062	-0.299	-0.126
	(0.299)	(0.241)	(0.385)	(0.281)
Heavy Metals	-0.044	0.075	0.243	0.087
	(0.153)	(0.076)	(0.188)	(0.091)
Traffic Emissions	-0.037	-0.199*	-0.294	-0.166
	(0.167)	(0.103)	(0.200)	(0.120)
Industrial Water Emissions	-0.078**	0.000	-0.093*	-0.056
	(0.035)	(0.037)	(0.054)	(0.050)
Agricultural Pesticides	-0.052*	0.036	-0.094**	-0.025
	(0.031)	(0.034)	(0.037)	(0.038)
Mining Water Emissions	-0.117***	-0.156***	-0.046	-0.110***
	(0.043)	(0.039)	(0.053)	(0.043)
Other Inputs:				
Mother's Height		0.010**		0.011*
		(0.005)		(0.006)
Mother's Age		0.010**		0.006
		(0.005)		(0.006)
Father's Age		0.003		0.003
		(0.004)		(0.006)
Disease Environment during Pregnancy		-0.228		-0.373**
		(0.151)		(0.169)
Mother consumes pre-natal vitamins		0.992***		0.365
		(0.233)		(0.243)
Per Capita Household Income during Pregnancy		0.001**		0.001
		(0.000)		(0.000)
Observations (N):	3059	3059	1884	1884
Hausman Test P-Value:	0	0.07	0	0.2

Notes: This table shows the impact of exposures on birth length for the entire sample of live-births with recorded lengths in columns 1 and 2, and for the subsample that never temporarily or permanently attrits. Column 1 estimates the impact of exposures alone while column 2 includes additional parental inputs affecting health (similarly for columns 3 and 4). Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.10:

Impacts of Exposures and Compensating Behaviors on Birth Length
Instrumented Exposure

	All Live Births: Birth Length Z-Score		Subsample that never attrits: Birth Length Z-Score	
	Non-Interacted	**Interacted**	**Non-Interacted**	**Interacted**
Non-Interacted Exposures				
CO, NOx, SOx, PM10	0.102	0.521	0.236	0.689
	(0.245)	(0.352)	(0.287)	(0.431)
Volatile Organic Compounds	-0.062	-0.378	-0.126	-0.464
	(0.241)	(0.338)	(0.281)	(0.422)
Heavy Metals	0.075	-0.319*	0.087	0.004
	(0.076)	(0.180)	(0.091)	(0.212)
Traffic Emissions	-0.199*	0.116	-0.166	-0.222
	(0.103)	(0.184)	(0.120)	(0.218)
Industrial Water Emissions	0.000	-0.072	-0.056	-0.113
	(0.037)	(0.057)	(0.050)	(0.081)
Agricultural Pesticides	0.036	-0.042	-0.025	-0.089**
	(0.034)	(0.038)	(0.038)	(0.043)
Mining Water Emissions	-0.156***	-0.164***	-0.110***	-0.088
	(0.039)	(0.059)	(0.043)	(0.067)
Behavioral Interactions with Exposures				
CO, NOx, SOx, PM10 **AND** Prenatal Vitamins		-0.248***		-0.135
		(0.072)		(0.098)
Volatile Organic Compounds **AND** Prenatal Vitamins		0.237**		0.128
		(0.100)		(0.130)
Heavy Metals **AND** Prenatal Vitamins		0.553***		0.524***
		(0.152)		(0.182)
Traffic Emissions **AND** Prenatal Vitamins		0.109*		0.129
		(0.064)		(0.081)
Industrial Water Emissions **AND** Prenatal Vitamins		-0.064		-0.032
		(0.066)		(0.090)
Agricultural Pesticides **AND** Prenatal Vitamins		-0.039		-0.021
		(0.053)		(0.067)
Mining Water Emissions **AND** Prenatal Vitamins		-0.021		-0.035
		(0.054)		(0.068)
Observations (N):	3059	3059	1884	1884
Hausman Test P-Value:	0.07		0.2	

Notes: This table shows results for the same outcome and samples as table however the measures of exposure are interacted with a binary variable indicating the mother's consumption of prenatal vitamins in columns 2 and 4. The consumption of prenatal vitamins represents a behavior of the mother aimed at improving the health of the child. Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.11:

Health Production Function: Height Throughout Life
Instrumented Exposure

	Birth Length Z-Score	Age 1 Height Z-Score	Age 2 Height Z-Score	Adult Height Z-Score
Fetal and Early Life Exposures				
CO, NOx, SOx, PM10	0.102	0.038	0.046	-0.121
	(0.245)	(0.235)	(0.297)	(0.192)
Volatile Organic Compounds	-0.062	0.161	0.322	0.134
	(0.241)	(0.221)	(0.278)	(0.183)
Heavy Metals	0.075	-0.095	-0.193**	-0.042
	(0.076)	(0.063)	(0.086)	(0.054)
Traffic Emissions	-0.199*	-0.066	0.040	-0.009
	(0.103)	(0.083)	(0.117)	(0.073)
Industrial Water Emissions	0.000	-0.106***	-0.179***	-0.081**
	(0.037)	(0.038)	(0.046)	(0.033)
Agricultural Pesticides	0.036	0.069*	0.021	0.001
	(0.034)	(0.036)	(0.050)	(0.030)
Mining Water Emissions	-0.156***	-0.098***	-0.126**	-0.033
	(0.039)	(0.037)	(0.054)	(0.032)
Other Inputs:				
Mother's Height	0.010**	0.033***	0.018***	0.061***
	(0.005)	(0.005)	(0.007)	(0.004)
Mother's Age	0.010**	-0.004	-0.024***	-0.001
	(0.005)	(0.006)	(0.009)	(0.005)
Father's Age	0.003	-0.012**	-0.001	-0.003
	(0.004)	(0.005)	(0.006)	(0.004)
Disease Environment during Pregnancy	-0.228	-0.005	0.466**	0.016
	(0.151)	(0.149)	(0.194)	(0.119)
Mother consumes pre-natal vitamins	0.992***	0.939***	0.071	-0.002
	(0.233)	(0.248)	(0.381)	(0.196)
Per Capita Household Income during Pregnancy	0.001**	0.001	-0.002*	-0.000
	(0.000)	(0.001)	(0.001)	(0.000)
Mother's Highest Achieved Education		0.045	0.418***	0.129***
		(0.061)	(0.085)	(0.042)
Per Capita Household Income at Age 1		-0.000	-0.001	-0.000
		(0.001)	(0.001)	(0.000)
Observations (N):	3059	2816	2663	2129
Hausman Test P-Value:	0.07	0.06	0	0.78

Notes: The sample for results shown in column 1: all live-born children with recorded length measurement;, column 2: all children with recorded height in the 6th wave (child age 1) or, for those absent in wave 6, measurements recorded in surrounding waves; columns 3 and 4: similar to column 2. Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.12:

Health Production Function: Height Throughout Life for Non-Attritors
Instrumented Exposure

	Birth Length Z-Score	Age 1 Height Z-Score	Age 2 Height Z-Score	Adult Height Z-Score
Fetal and Early Life Exposures				
CO, NOx, SOx, PM10	0.236	-0.028	0.020	-0.056
	(0.287)	(0.275)	(0.452)	(0.223)
Volatile Organic Compounds	-0.126	0.193	0.671	0.069
	(0.281)	(0.260)	(0.433)	(0.210)
Heavy Metals	0.087	-0.113	-0.050	-0.042
	(0.091)	(0.075)	(0.145)	(0.062)
Traffic Emissions	-0.166	-0.024	-0.199	0.022
	(0.120)	(0.100)	(0.186)	(0.083)
Industrial Water Emissions	-0.056	-0.104**	-0.246***	-0.090**
	(0.050)	(0.050)	(0.080)	(0.040)
Agricultural Pesticides	-0.025	0.055	-0.009	0.018
	(0.038)	(0.040)	(0.066)	(0.033)
Mining Water Emissions	-0.110***	-0.090**	-0.125*	-0.048
	(0.043)	(0.041)	(0.074)	(0.034)
Other Inputs:				
Mother's Height	0.011*	0.036***	0.030***	0.063***
	(0.006)	(0.006)	(0.008)	(0.005)
Mother's Age	0.006	-0.006	-0.011	0.003
	(0.006)	(0.007)	(0.009)	(0.005)
Father's Age	0.003	-0.012**	-0.011	-0.006
	(0.006)	(0.006)	(0.008)	(0.005)
Disease Environment during Pregnancy	-0.373**	0.135	0.720***	0.035
	(0.169)	(0.168)	(0.227)	(0.134)
Mother consumes pre-natal vitamins	0.365	0.717***	-0.333	0.151
	(0.243)	(0.244)	(0.367)	(0.202)
Per Capita Household Income during Pregnancy	0.001	0.000	-0.002	-0.001
	(0.000)	(0.001)	(0.001)	(0.001)
Mother's Highest Achieved Education		0.059	0.424***	0.093**
		(0.059)	(0.096)	(0.047)
Per Capita Household Income at Age 1		-0.000	-0.001	0.000
		(0.001)	(0.001)	(0.000)
Observations (N):	1884	1884	1884	1884
Hausman Test P-Value:	0.2	0.5	0.31	0.88

Notes: This table shows results for the same outcomes as table 9 however the sample is restricted to the children that never temporarily or permanently attrited from the sample. Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.13:

Impacts of Exposures and Compensating Behaviors on Height Throughout Life
Instrumented Exposure

	Age 1 Height Z-Score		**Age 2 Height Z-Score**		**Adult Height Z-Score**	
	Non-interacted	**Interacted**	**Non-interacted**	**Interacted**	**Non-interacted**	**Interacted**
Fetal and Early Life Exposures						
CO, NOx, SOx, PM10	0.038	0.051	0.046	1.289***	-0.121	-0.753**
	(0.235)	(0.344)	(0.297)	(0.446)	(0.192)	(0.330)
Volatile Organic Compounds	0.161	0.470	0.322	-0.685	0.134	0.695**
	(0.221)	(0.327)	(0.278)	(0.457)	(0.183)	(0.339)
Heavy Metals	-0.095	0.109	-0.193**	0.050	-0.042	-0.108
	(0.063)	(0.151)	(0.086)	(0.121)	(0.054)	(0.088)
Traffic Emissions	-0.066	-0.435***	0.040	-0.085	-0.009	0.027
	(0.083)	(0.145)	(0.117)	(0.148)	(0.073)	(0.108)
Industrial Water Emissions	-0.106***	-0.198***	-0.179***	-0.336***	-0.081**	0.005
	(0.038)	(0.059)	(0.046)	(0.066)	(0.033)	(0.053)
Agricultural Pesticides	0.069*	-0.030	0.021	-0.066	0.001	0.012
	(0.036)	(0.040)	(0.050)	(0.048)	(0.030)	(0.034)
Mining Water Emissions	-0.098***	-0.016	-0.126**	-0.067	-0.033	-0.026
	(0.037)	(0.053)	(0.054)	(0.055)	(0.032)	(0.039)
Behavioral Interactions with Exposures						
CO, NOx, SOx, PM10 **AND** Mother's Education		-0.074		0.194		0.016
		(0.102)		(0.148)		(0.109)
Volatile Organic Compounds **AND** Mother's Education		-0.123		-0.496***		0.153
		(0.130)		(0.164)		(0.124)
Heavy Metals **AND** Mother's Education		-0.268		-0.133		0.030
		(0.186)		(0.174)		(0.131)
Traffic Emissions **AND** Mother's Education		0.141*		0.314***		-0.021
		(0.074)		(0.080)		(0.058)
Industrial Water Emissions **AND** Mother's Education		0.070		0.141*		-0.150**
		(0.072)		(0.083)		(0.066)
Agricultural Pesticides **AND** Mother's Education		0.079		0.173**		-0.026
		(0.062)		(0.074)		(0.053)
Mining Water Emissions **AND** Mother's Education		-0.010		-0.021		-0.027
		(0.059)		(0.076)		(0.055)
Other Production Function Inputs:	Yes	Yes	Yes	Yes	Yes	Yes
Observations (N):	2816	2816	2663	2663	2129	2129
Hausman Test P-Value:	0.06		0		0.78	

Notes: This table illustrates similar results to table 9. Birth length is omitted because the interactive term is different. The interactive term indicating behavioral compensation is mother's education, a binary indicating that the mother completed high school, and it is interacted with exposure measures in columns 2, 4 and 6. Columns 1, 3 and 5 are repeated from table 9. Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.14:

Comparison of Individual vs Joint Estimates of Exposure's Impact on Height
Instrumented Exposure

	Length at Birth Z-Score							
Fetal Exposures:								
CO, NOx, SOx, PM10	-0.122***							0.102
	(0.044)							(0.245)
Volatile Organic Compounds		-0.042						-0.062
		(0.038)						(0.241)
Heavy Metals			0.015					0.075
			(0.031)					(0.076)
Traffic Emissions				-0.077**				-0.199*
				(0.038)				(0.103)
Industrial Water Emissions					-0.034			0.000
					(0.028)			(0.037)
Agricultural Pesticides						-0.081***		0.036
						(0.022)		(0.034)
Mining Water Emissions							-0.124***	-0.156***
							(0.021)	(0.039)
Controls for Other Inputs:	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations (N):	3059	3059	3059	3059	3059	3059	3059	3059
	Adult Height Z-Score							
Fetal and Early Life Exposures								
CO, NOx, SOx, PM10	-0.091***							-0.121
	(0.034)							(0.192)
Volatile Organic Compounds		-0.094***						0.134
		(0.032)						(0.183)
Heavy Metals			-0.030					-0.042
			(0.033)					(0.054)
Traffic Emissions				-0.075**				-0.009
				(0.035)				(0.073)
Industrial Water Emissions					-0.088***			-0.081**
					(0.025)			(0.033)
Agricultural Pesticides						-0.029		0.001
						(0.021)		(0.030)
Mining Water Emissions							-0.040*	-0.033
							(0.020)	(0.032)
Other Production Function Inputs:	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations (N):	2129	2129	2129	2129	2129	2129	2129	2129

Notes: The final column of this table displays the results from the joint estimation of exposure to a variety of contaminants on birth length and adult height. These are the same results as displayed in column 1 and 4 of table 9. Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.15:

Health Production Function: Human Capital
Instrumented Exposure

	Non-Verbal Test Score at age 10-11	Math Test Score at age 10-11	Hourly Earnings at age 22-23
Fetal and Early Life Exposures			
CO, NOx, SOx, PM10	-0.437	1.920	-1.324
	(3.418)	(3.041)	(12.742)
Volatile Organic Compounds	-1.092	-0.286	2.532
	(3.502)	(3.430)	(12.874)
Heavy Metals	-1.005	-2.773***	4.796
	(1.045)	(0.983)	(3.816)
Traffic Emissions	1.362	1.078	-1.664
	(1.376)	(1.248)	(4.775)
Industrial Water Emissions	-1.309*	-1.742***	-5.037*
	(0.709)	(0.592)	(2.588)
Agricultural Pesticides	-0.508	0.039	2.932
	(0.635)	(0.475)	(2.237)
Mining Water Emissions	0.704	-0.405	0.588
	(0.716)	(0.517)	(2.315)
Other Inputs:			
Mother's Height	0.126	0.128**	2.324
	(0.084)	(0.059)	(6.057)
Mother's Age	0.124	-0.003	7.430*
	(0.077)	(0.078)	(4.511)
Father's Age	-0.093	0.067	-7.359
	(0.073)	(0.068)	(5.666)
Disease Environment during Pregnancy	-4.812*	-6.630***	10.314
	(2.611)	(1.778)	(13.861)
Mother consumes pre-natal vitamins	-2.999	0.911	-9.149
	(4.059)	(3.226)	(12.761)
Per Capita Household Income during Pregnancy	0.008	-0.002	0.055*
	(0.011)	(0.008)	(0.030)
Mother's Highest Achieved Education	2.324***	4.601***	4.127
	(0.871)	(0.686)	(3.091)
Per Capita Household Income at Age 1	0.016**	-0.000	0.002
	(0.007)	(0.006)	(0.023)
Observations (N):	2180	2167	1441
Hausman Test P-Value:	0.01	0	0

Notes: Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.16:

Human Capital and Exposure to Biological and Non-Biological Contaminants
Instrumented Exposure

	Non-Verbal Test Score at age 10-11	Math Test Score at age 10-11	Hourly Earnings at age 22-23
Fetal and Early Life Exposures			
CO, NOx, SOx, PM10	9.152	13.035	-22.556
	(10.205)	(8.839)	(34.941)
Volatile Organic Compounds	-13.117	-6.222	30.604
	(9.653)	(8.346)	(32.923)
Heavy Metals	0.567	1.321	-2.560
	(2.871)	(2.486)	(9.693)
Traffic Emissions	2.510	-1.463	6.002
	(3.566)	(3.065)	(11.840)
Industrial Water Emissions	5.296**	-0.491	-9.552
	(2.257)	(1.973)	(8.583)
Agricultural Pesticides	-0.012	-4.343**	0.987
	(2.211)	(1.933)	(7.694)
Mining Water Emissions	0.029	5.896**	4.263
	(2.770)	(2.404)	(9.756)
Interaction of Biological Exposures			
CO, NOx, SOx, PM10 **AND** Biological	-7.531**	-7.494***	-28.744**
	(3.146)	(2.711)	(11.792)
Volatile Organic Compounds **AND** Biological	6.972	-3.024	31.018*
	(4.799)	(4.140)	(17.746)
Heavy Metals **AND** Biological	2.166	-9.082**	-14.405**
	(2.792)	(4.282)	(7.120)
Traffic Emissions **AND** Biological	-2.756	-0.817	-14.239
	(2.823)	(2.426)	(9.828)
Industrial Water Emissions **AND** Biological	-11.225***	0.884	1.583
	(3.817)	(3.313)	(14.358)
Agricultural Pesticides **AND** Biological	-1.063	6.404**	-0.536
	(3.214)	(2.811)	(11.261)
Mining Water Emissions **AND** Biological	3.384	-6.015	-2.856
	(4.240)	(3.662)	(14.909)
Other Production Function Inputs:	Yes	Yes	Yes
Observations (N):	2180	2167	1441
Hausman Test P-Value:	0.7	0.8	0.98

Notes: Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table 4.17:

Health Production Function: Other Health Outcomes
Instrumented Exposure

	Low Birthweight	Acute Respiratory Illness Ages 0-2	Adult Height	Adult Stunting	Adult BMI
Fetal and Early Life Exposures					
CO, NOx, SOx, PM10	-0.110	1.371**	-2.573	-0.068	0.722
	(0.078)	(0.676)	(2.035)	(0.105)	(0.817)
Volatile Organic Compounds	0.078	-1.554**	1.653	-0.014	-0.497
	(0.078)	(0.636)	(1.934)	(0.098)	(0.777)
Heavy Metals	-0.006	0.474**	0.146	0.047	0.248
	(0.024)	(0.194)	(0.568)	(0.030)	(0.228)
Traffic Emissions	0.016	-0.303	0.319	-0.040	-0.031
	(0.033)	(0.262)	(0.778)	(0.041)	(0.312)
Industrial Water Emissions	0.019*	0.167	-0.958***	0.049***	-0.258*
	(0.012)	(0.107)	(0.347)	(0.016)	(0.139)
Agricultural Pesticides	-0.017	0.035	0.163	0.006	0.033
	(0.011)	(0.111)	(0.321)	(0.018)	(0.129)
Mining Water Emissions	0.027**	0.034	-0.288	-0.003	0.065
	(0.013)	(0.117)	(0.335)	(0.019)	(0.135)
Other Inputs:					
Mother's Height	-0.004***	0.030**	0.446***	-0.019***	-0.047***
	(0.002)	(0.015)	(0.043)	(0.002)	(0.017)
Mother's Age	-0.001	0.059***	0.046	0.006**	-0.015
	(0.002)	(0.019)	(0.052)	(0.003)	(0.021)
Father's Age	-0.000	-0.019	-0.013	-0.001	-0.006
	(0.001)	(0.014)	(0.045)	(0.002)	(0.018)
Disease Environment during Pregnancy	0.041	-0.561	1.318	0.061	0.503
	(0.048)	(0.441)	(1.260)	(0.068)	(0.506)
Mother consumes pre-natal vitamins	-0.212***	2.301***	1.705	0.094	0.053
	(0.074)	(0.840)	(2.081)	(0.134)	(0.836)
Per Capita Household Income during Pregnancy	0.000	0.001	-0.001	0.001**	0.003
	(0.000)	(0.002)	(0.005)	(0.000)	(0.002)
Mother's Highest Achieved Education		-0.892***	0.371	-0.081***	-0.101
		(0.182)	(0.441)	(0.030)	(0.177)
Per Capita Household Income at Age 1		0.006***	0.006	-0.000	0.000
		(0.002)	(0.004)	(0.000)	(0.001)
Observations (N):	3061	3061	2129	2129	2129
Hausman Test P-Value:	0.34	0	0.91	0.11	0.99

Notes: The outcomes low birthweight, acute respiratory illness and adult stunting are each binary and the model for estimating the impacts of exposure are linear probability. Instrumental variable probit models have also been estimated with similar marginal effects. Adult height in centimeters is shown in column 3 as opposed to adult height z-score previously shown for consistency with other height measures and because missing values are resplaced with available measures from earlier waves, creating variation in age. Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

Appendix A

Appendix

A.1 Household Decision-making

This appendix section displays additional tables for the second chapter of this dissertation, *Household Decision-making: The Efficiency of Resource Allocation in Indonesian Households*. Tables A.1 and A.2 describe the composition of sub-aggregate goods constructed from survey data on 14 food groups and 11 non-food groups of household expenditure and corresponding prices solicited from street stalls, shops, markets, farm stores and community informants in each locale of the Work and Iron Status Evaluation survey. Table A.2 describing prices also displays the weights obtained from the 2002 SUSENAS expenditure survey of households in Purworejo, Indonesia. These weights are used to aggregate the prices.

Tables A.3 through A.10 which follow mirror the tables in chapter 2 but display the results for a larger, 8 good demand system. The results are very similar and establish the robustness of the demand system specification. Moreover, the larger demand system allows one more test to be performed. The asymptotic distribution of singular values test is only performed for the null hypothesis of $rank(M) \leq 2$

with the smaller, 6 good demand system because the limited degrees of freedom do not allow for tests of higher rank. The degrees of freedom increase as the number of goods in the demand system increases and the 8 good demand system allows for tests of the null hypothesis of $rank(M) \leq 4$.

Table A.1:

Expenditure Categories

Composite Goods (6)	Composite Goods (8)	Disaggregated Goods	Detail
Grain	**Grain**	Rice	Hulled, uncooked
		Staples	Corn, sago/flour, cassava, tapioca, dried cassava, sweet potatoes, potatoes, yams
		Dried food	Noodles, rice noodles, uncooked noodles, macaroni, shrimp chips, other chips
Fruits and Vegetables	**Fruits and Vegetables**	Fruits	Papaya, mango, banana, apple, coconut and other fruits
		Vegetables	Kangkung, cucumber, spinach, mustard greens, tomatoes, cabbage, katuk, green beans, string beans and the like, beans like mung-beans, peanuts, soya-beans
Protein and Calories	**Protein**	Meat and Fish	Beef, mutton, goat, chicken, duck; salted meat and canned meat; fresh fish, salted fish, smoked fish
		Tofu, Tempe	
		Milk, Eggs	Eggs, fresh milk, canned milk, powdered milk, cheese
	High Calorie Food	Beverages	Drinking water, coffee, tea, cocoa, soft drinks like Fanta, Sprite, etc., alcoholic beverages
		Sugar	Javanese (brown sugar), granulated sugar
		Oil	Coconut oil, peanut oil, corn oil, palm oil
		Spices	Sweet and salty soy sauce, salt, shrimp paste, bottled chili sauce, tomato sauce, shallot, garlic, chili, candle nuts, corriander
		Prepared food	
Tobacco	**Tobacco**	Tobacco	Cigarettes, tobacco, betel nut
Housing	**Home Goods**	Utilities and Transportation	Electricity, water, fuel, telephone, transportion (bus fare, cab fare, etc.) vehicle repair costs, gasoline
		Household Items	Laundry soap, cleaning supplies, personal toiletries, domestic servants
		Household equipment and repair	Tables, chairs, kitchen tools, bed sheets, towels, repairs
	Rent/Mortgage	Rent paid	
		Rent would pay	
Human Capital	**Human Capital**	Clothing	Shoes, hats, shirts, pants, children clothing
		Education	Fees, tuition, books, school supplies, transport, meals and housing expenses
		Medical Costs	hospitalization costs, clinic charges, physician's fee, traditional healer's fee, medicines
		Ritual Ceremonies, Charities and Gifts	weddings, circumcisions, tithe, charities, gifts

Table A.2:

Composite Prices			
Individual Good	Price Source	Weight in Composite Goods (8) Prices	Weight in Composite Goods (6) Prices
		Grain	**Grain**
Rice	Toko	0.41	0.41
Cassava	Pasar	0.01	0.01
Cassava Chips	Pasar	0.07	0.07
Cassava Leaves	Pasar	0.02	0.02
Corn	Pasar	0.03	0.03
Flour	Toko	0.09	0.09
Noodle	Toko	0.17	0.17
Potato	Pasar	0.16	0.16
Sweet Cassava	Pasar	0.04	0.04
		Fruits and Vegetables	**Fruits and Vegetables**
Apple	Pasar	0.18	0.18
Coconut	Pasar	0.05	0.05
Orange	Pasar	0.18	0.18
Papaya	Pasar	0.05	0.05
Salak	Pasar	0.09	0.09
Cabbage	Pasar	0.05	0.05
Carrot	Pasar	0.05	0.05
Cucumber	Pasar	0.05	0.05
Green beans	Pasar	0.05	0.05
Kangkung	Pasar	0.05	0.05
Lima beans	Pasar	0.05	0.05
Nuts	Pasar	0.05	0.05
Onion	Toko	0.05	0.05
Spinach	Pasar	0.05	0.05
Tomato	Pasar	0.05	0.05
		Protein	**Protein and High Calories**
Eggs	Toko	0.04	0.03
Milk Powder	Pasar	0.24	0.18
Sweet Milk	Toko	0.14	0.11
Mujair	Pasar	0.06	0.05
Pindang	Pasar	0.06	0.05
Teri	Pasar	0.02	0.02
Tongkol	Pasar	0.08	0.06
Beef	Pasar	0.18	0.14
Chicken	Pasar	0.08	0.06
Tempe	Toko	0.04	0.03
Tofu	Toko	0.04	0.03
		High Calorie Foods	
Tea	Toko	0.06	0.02
Coffee	Toko	0.06	0.02
Chili	Toko	0.06	0.02
Sugar	Toko	0.11	0.03
Garlic	Toko	0.06	0.02
Salt	Toko	0.17	0.02
Mineral Water	Toko	0.39	0.11
Oil	Toko	0.11	0.03
		Tobacco	**Tobacco**
Tobacco	Pasar	1	1
		Home Goods	**Housing**
Detergent	Toko	0.09	0.09
Soap	Toko	0.22	0.22
Gas (LPG)	Pasar	0.50	0.50
Kerosene	Toko	0.19	0.19
		Human Capital	**Human Capital**
Cotton	Pasar	0.02	0.02
Dress	Pasar	0.02	0.02
Pants	Pasar	0.90	0.90
Slippers	Toko	0.03	0.03
Notebook	Toko	0.90	0.90

Table A.3:

Budget Shares

	Single Adult	2 Adults	3+ Adults
Composite Goods (8):			
Grain	13.48	15.96	17.13
	(10.27)	(8.79)	(9.01)
Fruit and Vegetable	6.28	7.17	6.81
	(5.16)	(4.51)	(4.22)
Protein	9.11	12.39	12.15
	(8.32)	(7.71)	(7.08)
High Calorie	26.70	21.02	19.25
	(15.46)	(10.10)	(8.81)
Tobacco	3.15	5.27	5.69
	(6.25)	(6.54)	(6.40)
Human Capital	14.55	16.36	19.46
	(7.94)	(12.66)	(12.59)
Home Goods	9.05	10.27	10.46
	(13.45)	(7.97)	(7.45)
Rent/Mortgage	17.68	11.57	9.05
	(9.46)	(6.15)	(4.58)
Total Food and Non-food Shares:			
Food	58.73	61.80	61.03
	(15.39)	(13.95)	(13.45)
Non-Food	41.27	38.20	38.97
	(15.39)	(13.95)	(13.45)
Number of Observations	4010	19448	24271

Table A.4:

Composite Prices

	Single Adult	2 Adults	3+ Adults
Composite Prices (Rs10,000) (8 Goods):			
Grain	0.54	0.53	0.52
	(0.15)	(0.14)	(0.13)
Fruit and Vegetable	0.76	0.74	0.73
	(0.21)	(0.20)	(0.19)
Protein	3.80	3.69	3.64
	(0.92)	(0.87)	(0.82)
High Calorie	1.11	1.09	1.08
	(0.21)	(0.20)	(0.19)
Tobacco	0.43	0.42	0.41
	(0.06)	(0.06)	(0.06)
Human Capital	1.79	1.77	1.76
	(0.22)	(0.22)	(0.21)
Home Goods	3.33	3.19	3.12
	(1.07)	(1.03)	(0.98)

Table A.5:

Demand System (8 Goods) Estimates

	Grain	Protein	Fruits and Vegetables	High Calorie	Tobacco	Home Goods	Human Capital
Single Adult Households							
Log of Composite Prices							
Grain	2.29	-3.87	1.79	8.80	3.20	-0.53	-12.15**
	(4.54)	(3.73)	(2.38)	(5.93)	(2.38)	(2.91)	(5.50)
Protein	-8.32	1.33	6.97*	4.23	8.31**	-4.83	-9.41
	(6.94)	(5.70)	(3.63)	(9.07)	(3.64)	(4.45)	(8.41)
Fruits and Vegetables	-4.51	-0.02	0.47	3.44	-1.57	0.40	1.08
	(3.39)	(2.79)	(1.78)	(4.44)	(1.78)	(2.18)	(4.12)
High Calorie	-4.67	-5.36*	1.74	0.41	3.71*	-0.55	4.95
	(3.95)	(3.24)	(2.07)	(5.16)	(2.07)	(2.54)	(4.79)
Tobacco	-3.97	-3.89	0.60	7.29	-1.82	2.93	1.60
	(4.17)	(3.43)	(2.18)	(5.46)	(2.19)	(2.68)	(5.06)
Home Goods	-2.60	1.90	-1.79	-0.72	2.86**	1.44	-2.12
	(2.49)	(2.05)	(1.30)	(3.26)	(1.31)	(1.60)	(3.02)
Human Capital	7.42**	-3.94	0.31	-5.90	-1.18	3.87*	-1.70
	(3.49)	(2.87)	(1.83)	(4.57)	(1.83)	(2.24)	(4.24)
Multiple Adult Households							
Log of Composite Prices							
Grain	4.30***	0.78	-0.93**	-0.93	0.53	-0.19	-3.50***
	(0.85)	(0.76)	(0.45)	(1.00)	(0.56)	(0.65)	(1.17)
Protein	-3.21**	0.06	-0.41	10.17***	-0.66	-2.73***	-2.52
	(1.31)	(1.16)	(0.69)	(1.52)	(0.86)	(0.99)	(1.79)
Fruits and Vegetables	-0.31	-0.44	0.15	0.75	-0.54	-1.18**	1.81**
	(0.65)	(0.58)	(0.35)	(0.76)	(0.43)	(0.50)	(0.90)
High Calorie	-0.51	-0.07	0.02	-0.23	1.19**	0.15	-0.57
	(0.74)	(0.66)	(0.39)	(0.86)	(0.49)	(0.56)	(1.01)
Tobacco	0.42	-2.43***	0.27	2.47**	-0.60	-1.07	1.46
	(0.93)	(0.83)	(0.49)	(1.09)	(0.61)	(0.71)	(1.28)
Home Goods	0.06	-1.98***	-0.50*	1.25**	-0.51	0.05	1.54**
	(0.49)	(0.43)	(0.26)	(0.57)	(0.32)	(0.37)	(0.67)
Human Capital	1.64**	1.82***	0.46	-3.58***	0.90**	1.56***	-2.74***
	(0.69)	(0.61)	(0.36)	(0.80)	(0.45)	(0.52)	(0.94)
Additional Controls:							
Spline Per Capita Exp.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban/Rural Residence	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Composition	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table A.6:

Demand System (8 Goods) Estimates

	Grain	Protein	Fruits and Vegetables	High Calorie	Tobacco	Home Goods	Human Capital
Single Adult Households							
Log of Composite Prices							
Grain	2.29	-3.87	1.79	8.80	3.20	-0.53	-12.15**
	(4.54)	(3.73)	(2.38)	(5.93)	(2.38)	(2.91)	(5.50)
Protein	-8.32	1.33	6.97*	4.23	8.31**	-4.83	-9.41
	(6.94)	(5.70)	(3.63)	(9.07)	(3.64)	(4.45)	(8.41)
Fruits and Vegetables	-4.51	-0.02	0.47	3.44	-1.57	0.40	1.08
	(3.39)	(2.79)	(1.78)	(4.44)	(1.78)	(2.18)	(4.12)
High Calorie	-4.67	-5.36*	1.74	0.41	3.71*	-0.55	4.95
	(3.95)	(3.24)	(2.07)	(5.16)	(2.07)	(2.54)	(4.79)
Tobacco	-3.97	-3.89	0.60	7.29	-1.82	2.93	1.60
	(4.17)	(3.43)	(2.18)	(5.46)	(2.19)	(2.68)	(5.06)
Home Goods	-2.60	1.90	-1.79	-0.72	2.86**	1.44	-2.12
	(2.49)	(2.05)	(1.30)	(3.26)	(1.31)	(1.60)	(3.02)
Human Capital	7.42**	-3.94	0.31	-5.90	-1.18	3.87*	-1.70
	(3.49)	(2.87)	(1.83)	(4.57)	(1.83)	(2.24)	(4.24)
2 Adult Households							
Log of Composite Prices							
Grain	4.86***	-0.19	0.26	-0.76	0.34	0.18	-4.92***
	(1.29)	(1.20)	(0.70)	(1.63)	(0.82)	(1.03)	(1.78)
Protein	-3.41*	-1.92	-0.09	13.65***	0.71	-3.05*	-4.78*
	(2.00)	(1.86)	-1.08	(2.51)	(1.26)	(1.59)	(2.75)
Fruits and Vegetables	0.67	-0.08	0.41	0.70	-0.58	-2.35***	1.88
	(0.99)	(0.92)	(0.54)	(1.25)	(0.63)	(0.79)	(1.37)
High Calorie	-0.94	1.26	0.03	0.48	0.12	-0.80	-0.47
	(1.13)	(1.05)	(0.61)	(1.43)	(0.71)	(0.90)	(1.56)
Tobacco	1.76	-2.63**	0.66	1.32	-1.07	-2.23*	2.61
	(1.43)	(1.33)	(0.77)	(1.80)	(0.90)	(1.14)	(1.97)
Home Goods	0.62	-3.36***	-0.14	1.54*	-0.35	0.33	0.95
	(0.67)	(0.62)	(0.36)	(0.84)	(0.42)	(0.53)	(0.93)
Human Capital	2.66**	2.34**	0.22	-3.46***	0.10	2.16***	-4.04***
	(1.05)	(0.98)	(0.57)	(1.33)	(0.66)	(0.84)	(1.45)
3+ Adult Households							
Log of Composite Prices							
Grain	3.79***	1.62*	-1.83***	-0.84	0.49	-0.42	-2.50
	(1.14)	(0.97)	(0.59)	(1.24)	(0.77)	(0.83)	(1.53)
Protein	-3.08*	1.00	-0.45	7.86***	-1.61	-2.32*	-1.64
	(1.73)	(1.48)	(0.90)	(1.89)	(1.17)	(1.27)	(2.32)
Fruits and Vegetables	-1.02	-0.48	-0.05	0.77	-0.51	-0.35	1.94*
	(0.87)	(0.74)	(0.45)	(0.95)	(0.59)	(0.64)	(1.16)
High Calorie	-0.21	-1.07	0.08	-0.66	1.96***	0.82	-0.99
	(0.97)	(0.83)	(0.51)	(1.06)	(0.66)	(0.72)	(1.31)
Tobacco	-0.59	-2.29**	0.02	3.37**	-0.34	-0.23	0.27
	(1.23)	(1.05)	(0.64)	(1.34)	(0.83)	(0.90)	(1.65)
Home Goods	-0.70	-0.59	-0.85**	0.89	-0.70	-0.16	1.98**
	(0.70)	(0.60)	(0.37)	(0.77)	(0.48)	(0.52)	(0.95)
Human Capital	0.81	1.44*	0.64	-3.66***	1.60***	1.09	-1.98
	(0.91)	(0.78)	(0.47)	(0.99)	(0.62)	(0.67)	(1.22)
Additional Controls:							
Spline Per Capita Exp.	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban/Rural Residence	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Composition	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Household Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Table A.7:

Tests of the Unitary and Collective Rationality Models: 8 Good Demand System with Household Fixed Effects

	Single Adult	Multiple Adults
Tests of Symmetry:		
Wald Statistic from Joint Test	20.23	168.55
P-Value	0.51	0.00
Tests of Collective Rationality:		
Browning and Chiappori Linear Test		
Rank less than or equal to 2		
Wald Statistic	5.21	103.56
P-Value	0.88	0.00
Borderline Singular Value Test		
Rank less than or equal to 2		
P-Value	0.19	0.03
Rank less than or equal to 4		
P-Value	0.11	0.01
Asymptotic Distribution of Singular Values Test		
Rank less than or equal to 2		
Wald Statistic	14.51	489.34
P-Value	0.95	0.00
Rank less than or equal to 4		
Wald Statistic	42.33	560.51
P-Value	0.00	0.00

Table A.8:

Tests of the Unitary and Collective Rationality Models: 8 Good Demand System No Fixed Effects

	Single Adult	Multiple Adults
Tests of Symmetry:		
Wald Statistic from Joint Test	10.16	290.66
P-Value	0.98	0.00
Tests of Collective Rationality:		
Browning and Chiappori Linear Test		
Rank less than or equal to 2		
Wald Statistic	1.48	186.11
P-Value	0.99	0.00
Borderline Singular Value Test		
Rank less than or equal to 2		
P-Value	0.18	0.67
Rank less than or equal to 4		
P-Value	0.14	0.02
Asymptotic Distribution of Singular Values Test		
Rank less than or equal to 2		
Wald Statistic	8.14	755.06
P-Value	0.99	0.00
Rank less than or equal to 4		
Wald Statistic	3.00	634.77
P-Value	0.99	0.00

Table A.9:

Tests of the Unitary and Collective Rationality Models:
8 Good Demand System with Household Fixed Effects

	Single Adult	2 Adults	3+ Adults
Tests of Symmetry:			
Wald Statistic from Joint Test	20.08	148.60	115.25
P-Value	0.46	0.00	0.00
Tests of Collective Rationality:			
Browning and Chiappori Linear Test			
Rank less than or equal to 2			
Wald Statistic	3.45	47.52	78.69
P-Value	0.97	0.00	0.00
Borderline Singular Value Test			
Rank less than or equal to 2			
P-Value	0.99	0.56	0.00
Rank less than or equal to 4			
P-Value	0.98	0.40	0.02
Asymptotic Distribution of Singular Values Test			
Rank less than or equal to 2			
Wald Statistic	34.40	136.63	255.53
P-Value	0.55	0.00	0.00
Rank less than or equal to 4			
Wald Statistic	30.11	121.11	300.96
P-Value	0.02	0.00	0.00

Table A.10:

Tests of the Unitary and Collective Rationality Models:
8 Good Demand System No Fixed Effects

	Single Adult	2 Adults	3+ Adults
Tests of Symmetry:			
Wald Statistic from Joint Test	7.95	242.31	176.06
P-Value	0.99	0.00	0.00
Tests of Collective Rationality:			
Browning and Chiappori Linear Test			
Rank less than or equal to 2			
Wald Statistic	79.43	45.87	18.41
P-Value	0.00	0.00	0.24
Borderline Singular Value Test			
Rank less than or equal to 2			
P-Value	0.43	0.27	0.27
Rank less than or equal to 4			
P-Value	1.00	1.00	1.00
Asymptotic Distribution of Singular Values Test			
Rank less than or equal to 2			
Wald Statistic	410.19	436.29	51.02
P-Value	0.00	0.00	0.05
Rank less than or equal to 4			
Wald Statistic	27.70	517.89	152.81
P-Value	0.03	0.00	0.00

A.2 Are Rural Markets Complete? Prices, Profits and Recursion

This appendix section displays additional tables for the third chapter of this dissertation, *Are Rural Markets Complete? Prices, Profits and Recursion.* Similar to the previous appendix section, tables A.11 and A.12 describe the composition of sub-aggregate goods constructed from survey data on 14 food groups and 11 non-food groups of household expenditure and corresponding prices solicited from street stalls, shops, markets, farm stores and community informants in each locale of the Work and Iron Status Evaluation survey. However, whereas the previous chapter constructed sub-aggregate expenditure groups of 8 and 6 goods, the main analysis of this chapter constricts the size of the demand system even further to 4 goods and the appendix displays results for a 7 good demand system. Table A.2 describing prices also displays the weights obtained from the 2002 SUSENAS expenditure survey of households in Purworejo, Indonesia. These weights are used to aggregate the prices.

Tables A.13 through A.16 which follow mirror the tables in chapter 2 but display the results for a larger, 7 good demand system. The results are very similar both to the main results presented in chapter 3 but also to the results presented in chapter 2. The similarity of results across demand system size establishes the robustness of the demand system specification. Moreover, the larger demand system allows one more test to be performed.

Table A.11:

Expenditure Categories and Budget Shares

Composite Good	Disaggregated Good	Detail
Grain	Rice	Hulled, uncooked
	Staples	Corn, sago/flour, cassava, tapioca, dried cassava, sweet potatoes, potatoes, yams
	Dried Food	Noodles, rice noodles, uncooked noodles, macaroni, shrimp chips, other chips
Other Food	Meat and Fish	Beef, mutton, goat, chicken, duck, salted meat and canned meat, fresh fish, salted fish, smoked fish
	Vegetables	Kangkung, cucumber, spinach, mustard greens, tomatoes, cabbage, katuk, green beans, string beans and the like, beans like mung-beans, peanuts, soya-beans
	Fruits	Papaya, mango, banana and the like
	Tofu, Tempe	
	Milk, Eggs	Eggs, fresh milk, canned milk, powdered milk, cheese
	Sugar	Javanese (brown) sugar, granulated sugar
	Oil	Coconut oil, peanut oil, corn oil, palm oil
	Spices	Sweet and salty soy sauce, salt, shrimp paste, chili sauce, tomato sauce, shallot, garlic, chili, candle nuts, coriander
	Beverages and Other Drinks/Consumer Products	Drinking water, coffee, tea, cocoa, soft drinks like Fanta, Sprite, etc., alcoholic beverages like beer, wine
	Tobacco	Cigarettes, tobacco, betel nut
	Prepared food	
Home Goods	Utilities and Transportation	Electricity, water, fuel, transportation, including bus fare, cab fare, vehicle repair costs, gasoline
	Household Items	Laundry soap, cleaning supplies, personal toiletries, domestic servants
	Household Equipment and Repair	Tables, chairs, kitchen tools, bed sheets, towels, repairs
	Rent you do pay	
	Rent would pay if renting	
Human Capital	Clothing for Children & Adults	Shoes, hats, shirts, pants, clothing for children
	Education	Fees, tuition, books, school supplies, transport, meals and housing expenses
	Medical Costs	Hospitalization costs, clinic charges, physician's fee, traditional healer's fee, medicines
	Ritual Ceremonies, Charities, and Gifts	Weddings, circumcisions, tithe, charities, gifts

Notes: Table provides a guide to the disaggregated goods in the WISE consumption module that are included in each of the composite goods used in the demand system estimation.

Table A.12:

Composite Price Sources and Weights

Composite Good	Individual Good	Price Source	Weight in Composite Price
Grain	Cassava	Pasar	0.01
	Cassavachip	Pasar	0.07
	Cassava leaves	Pasar	0.02
	Corn	Pasar	0.03
	Flour	Toko	0.09
	Noodle	Toko	0.17
	Potato	Pasar	0.16
	Rice	Toko	0.41
	Sweet Cassava	Pasar	0.04
Other Food	Apple	Pasar	0.04
	Beef	Pasar	0.09
	Cabbage	Pasar	0.01
	Carrot	Pasar	0.01
	Chicken	Pasar	0.04
	Chili	Toko	0.01
	Cigarettes	Toko	0.14
	Coconut	Pasar	0.002
	Coffee	Toko	0.01
	Cucumber	Pasar	0.01
	Eggs	Toko	0.02
	Garlic	Toko	0.01
	Green Bean	Pasar	0.01
	Kangkung	Pasar	0.01
	Lima Bean	Pasar	0.01
	Milk Powder	Pasar	0.12
	Mineral Water	Pasar	0.07
	Mujair	Pasar	0.03
	Nuts	Pasar	0.01
	Oil	Toko	0.02
	Onions	Toko	0.01
	Oranges	Pasar	0.04
	Papaya	Pasar	0.0002
	Pindang	Pasar	0.03
	Salak	Pasar	0.02
	Salt	Toko	0.003
	Spinach	Pasar	0.005
	Sugar	Toko	0.02
	Sweet Milk	Toko	0.07
	Tea	Toko	0.01
	Tempe	Toko	0.02
	Teri	Pasar	0.01
	Tobacco	Pasar	0.03
	Tofu	Pasar	0.02
	Tomato	Pasar	0.01
	Tongkol	Pasar	0.04
Home Goods	Detergent	Toko	0.09
	Gas (LPG)	Pasar	0.50
	Kerosene	Toko	0.19
	Soap	Toko	0.22
Human Capital	Cotton	Pasar	0.02
	Dresses	Pasar	0.02
	Notebook	Toko	0.90
	Pants	Pasar	0.02
	Slippers	Toko	0.03

Notes: Table summarizes the individual prices that are utilized in constructing composite prices. Weights are determined using the 2002 SUSENAS detailed expenditure survey, restricting the sample to Purworejo.

Table A.13:

Expanded Demand System Estimates

	Share of Household Expenditure on [...]						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Grain	**Protein**	**Fruit and Vegetables**	**High Calorie Food**	**Tobacco**	**Home Goods**	**Human Capital**
Composite Prices							
Grain	2.70***	-0.98	-0.44	-0.30	0.00	-0.12	-0.87
	(0.97)	(0.85)	(0.52)	(1.15)	(0.62)	(0.73)	(1.32)
Protein	-1.81	0.73	-1.07	5.70***	-1.18	0.36	-2.74
	(1.56)	(1.37)	(0.85)	(1.92)	(1.02)	(1.25)	(2.18)
Fruit and Veg	-0.12	0.82	1.20***	-2.77***	-0.93*	0.03	1.77
	(0.80)	(0.73)	(0.44)	(0.94)	(0.53)	(0.62)	(1.10)
High Calorie	0.97	-0.46	0.32	-0.45	1.08***	-0.49	-0.97
	(0.60)	(0.54)	(0.32)	(0.73)	(0.39)	(0.48)	(0.86)
Tobacco	0.84	-2.22**	1.15**	-1.04	-0.77	1.03	0.99
	(1.03)	(0.90)	(0.55)	(1.24)	(0.69)	(0.82)	(1.39)
Home Goods	-1.33	-2.15***	-0.98**	5.88***	-0.39	-0.21	-0.81
	(0.84)	(0.76)	(0.44)	(1.02)	(0.55)	(0.65)	(1.21)
Human Capital	2.16**	1.24*	-0.62	-0.89	1.36**	0.94	-4.20***
	(0.88)	(0.75)	(0.47)	(1.01)	(0.54)	(0.65)	(1.19)
Farm Input Prices							
Rice seed	1.15	-0.96	1.44***	-5.24***	0.63	2.27***	0.70
	(0.87)	(0.81)	(0.48)	(1.06)	(0.57)	(0.72)	(1.17)
Kangkung Seed	-0.49	0.08	0.58***	0.73**	0.28	-0.68**	-0.51
	(0.32)	(0.28)	(0.17)	(0.35)	(0.20)	(0.27)	(0.45)
Insecticide	-0.18	0.54	0.70	-1.68*	-0.58	-1.21**	2.41**
	(0.80)	(0.70)	(0.45)	(0.92)	(0.51)	(0.60)	(1.06)
Fertilizer	2.21***	0.43	0.37	1.56*	-0.56	0.16	-4.17***
	(0.74)	(0.67)	(0.41)	(0.89)	(0.47)	(0.57)	(1.03)
Splines in log(PCE)							
0-25th Percentile	2.25***	3.75***	0.29	5.11***	2.22***	-14.93***	1.31**
	(0.61)	(0.36)	(0.24)	(0.54)	(0.30)	(0.38)	(0.55)
25th-50th Percentile	-4.12***	3.98***	0.05	5.51***	1.74***	-11.52***	4.35***
	(0.67)	(0.54)	(0.33)	(0.76)	(0.42)	(0.44)	(0.79)
50th-75th Percentile	-3.28***	2.56***	-1.26***	5.02***	1.01***	-11.34***	7.29***
	(0.61)	(0.57)	(0.29)	(0.75)	(0.38)	(0.47)	(0.98)
75-100 Percentile	-0.92**	1.73***	-1.05***	1.67***	-0.34	-8.81***	7.72***
	(0.36)	(0.43)	(0.19)	(0.52)	(0.24)	(0.30)	(0.92)
Household Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Joint Test of Input Prices							
F statistic	3.18	0.72	7.30	7.96	1.87	4.86	4.98
p-value	0.01	0.58	0.00001	0.000002	0.11	0.0007	0.0005
Observations	29101	29101	29101	29101	29101	29101	29101
N. Households	3825	3825	3825	3825	3825	3825	3825

Notes: See Table 2.

*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

Table A.14:

Expanded Demand System Input Price Ratios

	Share of Household Expenditure on [...]						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Grain	**Protein**	**Fruit and Vegetables**	**High Calorie Food**	**Tobacco**	**Home Goods**	**Human Capital**
Ratio of [...] to [...]							
Kangkung Seed to Rice Seed	-0.42	-0.09	0.40**	-0.14**	0.44	-0.30**	-0.73
	(0.40)	(0.29)	(0.19)	(0.07)	(0.54)	(0.15)	(1.32)
Insecticide to Rice Seed	-0.15	-0.56	0.48	0.32*	-0.92	-0.53	3.46
	(0.70)	(0.87)	(0.35)	(0.19)	(1.15)	(0.32)	(5.99)
Fertilizer to Rice Seed	1.92	-0.45	0.26	-0.30*	-0.89	0.07	-5.98
	(1.57)	(0.80)	(0.30)	(0.18)	(1.11)	(0.25)	(10.09)
Insecticide to Kangkung Seed	0.36	6.50	1.19	-2.30	-2.07	1.77	-4.76
	(1.65)	(23.05)	(0.83)	(1.70)	(2.35)	(1.08)	(4.77)
Fertilizer to Kangkung Seed	-4.54	5.20	0.63	2.13	-2.02	-0.24	8.23
	(3.32)	(19.53)	(0.74)	(1.67)	(2.27)	(0.83)	(7.74)
Insecticide to Fertilizer	-0.08	1.25	1.88	-1.08	1.02	-7.38	-0.58**
	(0.35)	(2.91)	(2.77)	(0.71)	(1.45)	(24.69)	(0.25)
Observations	29101	29101	29101	29101	29101	29101	29101
N. of Households	3825	3825	3825	3825	3825	3825	3825

Notes: See Table 3.

** Significant at the 5% level, * Significant at the 10% level

Table A.15:

Separation Ratio Test Results for Expanded Demand System (*p*-values)

Summary	
N. of Pairwise Ratios	126
N. of Rejections at 5%	18
N. of Rejections at 10%	28

Consumption Goods		*Ratio Test Results*						
			Rice Seed to […]		Kangkung to […]		Insecticide to	All 6
Good A	*Good B*	Kangkung Seed	Insecticide	Fertilizer	Insecticide	Fertilizer	Fertilizer	Ratios
Grain	Protein	0.489	0.689	0.210	0.512	0.572	0.455	0.804
	Fruit and Vegetables	**0.075**	0.469	**0.088**	0.663	**0.015**	0.190	0.130
	High Calorie Food	0.323	0.514	**0.006**	0.267	**0.039**	0.194	0.105
	Tobacco	0.183	0.565	0.169	0.372	0.532	0.277	0.623
	Home Goods	0.760	0.659	**0.054**	0.536	**0.092**	**0.088**	0.284
	Human Capital	0.802	0.253	0.113	0.237	**0.042**	0.180	0.270
Protein	Fruit and Vegetables	0.318	0.258	0.381	0.571	0.596	0.884	0.753
	High Calorie Food	0.865	0.287	0.847	0.457	0.794	0.284	0.905
	Tobacco	0.370	0.795	0.729	0.475	0.508	0.940	0.962
	Home Goods	0.556	0.969	0.472	0.648	0.511	0.481	0.974
	Human Capital	0.438	0.266	0.273	0.578	0.913	0.256	0.789
Fruit and Vegetables	High Calorie Food	**0.007**	0.664	0.106	**0.048**	0.371	0.129	**0.015**
	Tobacco	0.946	0.173	0.200	0.155	0.184	0.755	0.379
	Home Goods	**0.002**	**0.034**	0.643	0.647	0.428	0.411	**0.054**
	Human Capital	0.254	0.183	**0.013**	**0.031**	**0.014**	**0.060**	**0.042**
High Calorie Food	Tobacco	**0.095**	0.164	0.466	0.941	0.129	0.138	0.328
	Home Goods	0.248	**0.009**	0.200	**0.038**	0.140	0.320	0.139
	Human Capital	0.360	**0.054**	**0.002**	0.438	0.144	0.369	**0.048**
Tobacco	Home Goods	**0.095**	0.712	0.257	0.137	0.375	0.321	0.474
	Human Capital	0.336	0.247	0.397	0.546	0.133	0.109	0.406
Home Goods	Human Capital	0.620	**0.047**	**0.011**	**0.042**	**0.035**	**0.080**	**0.095**
	Overall	0.521						

Notes: See Table 4.

Table A.16:

Demand Systems for Stratified Samples

	Household Land Holdings Less than the Community Mean *Share of Household Expenditure on […]*				**Household Land Holdings Greater than the Community Mean** *Share of Household Expenditure on […]*			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
	Grain	**Other Food**	**Home Goods**	**Human Capital**	**Grain**	**Other Food**	**Home Goods**	**Human Capital**
log of Composite Prices								
Grain	1.85*	-0.89	-0.57	-0.39	1.98	0.17	-1.30	-0.85
	(1.04)	(1.45)	(0.75)	(1.33)	(1.30)	(2.11)	(1.16)	(2.11)
Other Food	-0.75	5.45*	-1.47	-3.23	0.06	1.00	1.70	-2.76
	(2.10)	(2.91)	(1.50)	(2.67)	(2.65)	(4.30)	(2.37)	(4.29)
Home Goods	-0.46	2.31*	-0.62	-1.23	-3.16***	3.56*	-0.48	0.08
	(0.98)	(1.36)	(0.70)	(1.25)	(1.22)	(1.98)	(1.09)	(1.97)
Human Capital	3.26***	0.64	0.28	-4.19***	-0.87	1.45	2.67**	-3.25
	(0.99)	(1.38)	(0.71)	(1.26)	(1.26)	(2.05)	(1.13)	(2.04)
log of Farm Input Prices								
Rice Seed	1.87*	-5.17***	2.38***	0.92	-1.23	-2.98	2.60**	1.61
	(1.01)	(1.41)	(0.73)	(1.29)	(1.30)	(2.11)	(1.16)	(2.10)
Kangkung Seed	-0.56	1.89***	-0.65**	-0.67	-0.82*	1.00	-0.54	0.36
	(0.37)	(0.51)	(0.26)	(0.47)	(0.47)	(0.76)	(0.42)	(0.75)
Insecticide	2.73***	-0.28	0.47	-2.92***	1.20	4.04**	-0.03	-5.21***
	(0.88)	(1.23)	(0.63)	(1.12)	(1.13)	(1.84)	(1.01)	(1.83)
Fertilizer	-0.65	-1.03	-1.04	2.72**	1.72	-0.86	-1.38	0.51
	(0.91)	(1.26)	(0.65)	(1.15)	(1.17)	(1.90)	(1.05)	(1.90)
Splines in log(PCE)								
0-25th Percentile	2.29***	11.46***	-15.10***	1.34**	2.02***	11.03***	-14.58***	1.52
	(0.45)	(0.63)	(0.32)	(0.57)	(0.77)	(1.25)	(0.69)	(1.25)
25th-50th Percentile	-3.37***	11.33***	-11.64***	3.68***	-5.92***	11.26***	-11.25***	5.91***
	(0.70)	(0.97)	(0.50)	(0.89)	(0.97)	(1.57)	(0.86)	(1.56)
50th-75th Percentile	-2.71***	7.95***	-12.08***	6.84***	-4.54***	5.93***	-9.97***	8.58***
	(0.66)	(0.91)	(0.47)	(0.83)	(0.79)	(1.28)	(0.70)	(1.28)
75th-100th Percentile	-0.09	2.70***	-8.93***	6.31***	-1.89***	1.27**	-8.74***	9.36***
	(0.34)	(0.48)	(0.25)	(0.44)	(0.34)	(0.55)	(0.30)	(0.54)
Household Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	19,711	19,711	19,711	19,711	9,390	9,390	9,390	9,390

Notes: Table reports demand system estimates similiar to those in Table 2, but for stratified sample. Households are divided by whether they are small or large landowners, where small is defined as owning less than or equal to the within community mean. The majority of households fall within the small category. As before, outcomes are shares of household expenditure on the composite good in each column, and all prices are expressed in real terms as the log of 2002 Rp0,000. Knots in the log PCE distribution are placed at the 25%, 50% and 75% percentile. Additional controls include the education and and age of the primary male and female within the household, an indicators for whether or not the household is in an urban area, household composition, and indicators for the wave, year, and season. Standard errors appear below the point estimates and are calculated allowing for clustering at the household level.

*** Significant at the 1% level, ** Significant at the 5% level, * Significant at the 10% level

A.3 Environment and Health: The Effects of Early-Life Exposures to Environmental Contaminants in the Philippines

This appendix section displays additional figures and tables for the fourth and final chapter of this dissertation, *Environment and Health: The Effects of Early-Life Exposures to Environmental Contaminants in the Philippines*. Beginning with the figures, figure A.1 displays the map of Metro Cebu with the pollution sources and sample barangays highlighted. The colors of the highlighted sample barangays vary by the average reported monthly rent of the household. If environmental quality were capitalized in housing prices the most expensive housing would be found at greater distances from the sources of pollution but in the context of Metro Cebu the opposite is true. Figure A.2 shows that pregnancies more likely to end during the Habagat (May-September) are distributed throughout Metro Cebu without any pattern indicating fertility planning related to environmental exposures. Figure A.3 shows that there is no particular geographic pattern to the distribution of pregnancies more likely to end between January and April 1984.

Tables A.17 and A.18 examine the exclusion restriction of the instruments and the attrition in the sample. Table A.17 compares the full sample to the non-agricultural household sample estimates of exposure's impact on birth length and adult height. Table A.18 shows the regressions of instrumented and non-instrumented exposure on three definitions of attrition.

A.3.1 Figures

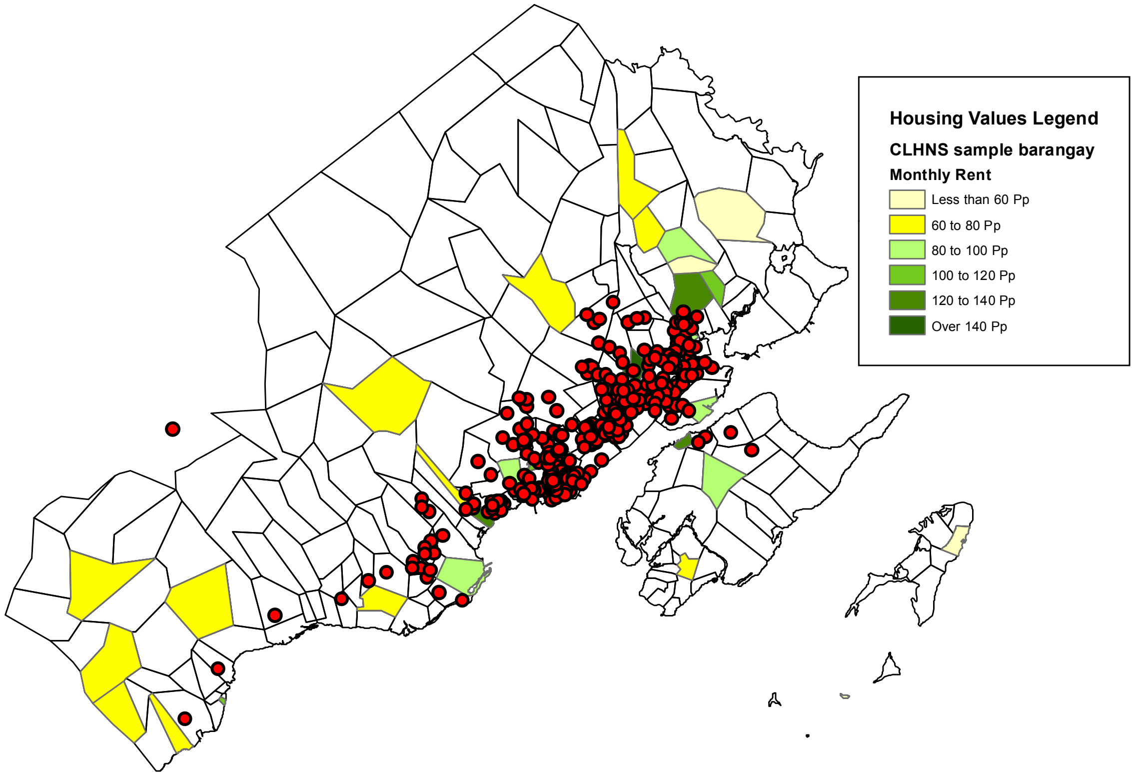

FIGURE A.1: Geographic distribution of Barangay Average Monthly Housing Rent

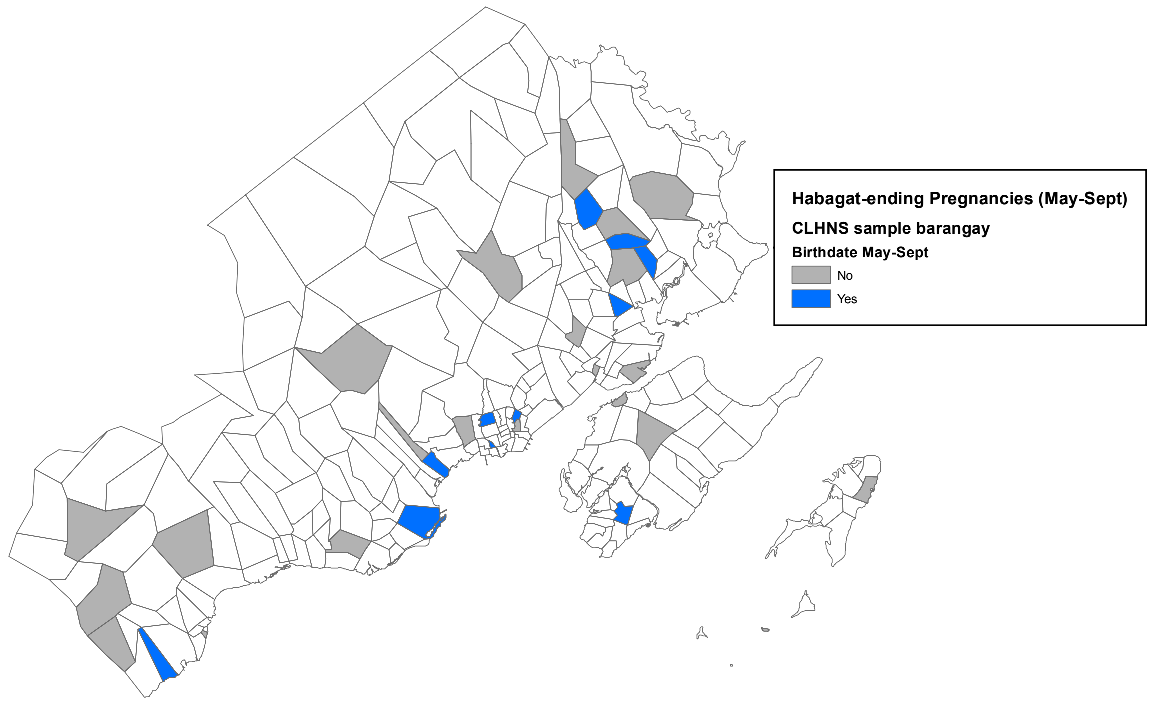

FIGURE A.2: Geographic distribution of Habagat-ending Pregnancies (May-Sept 1983)

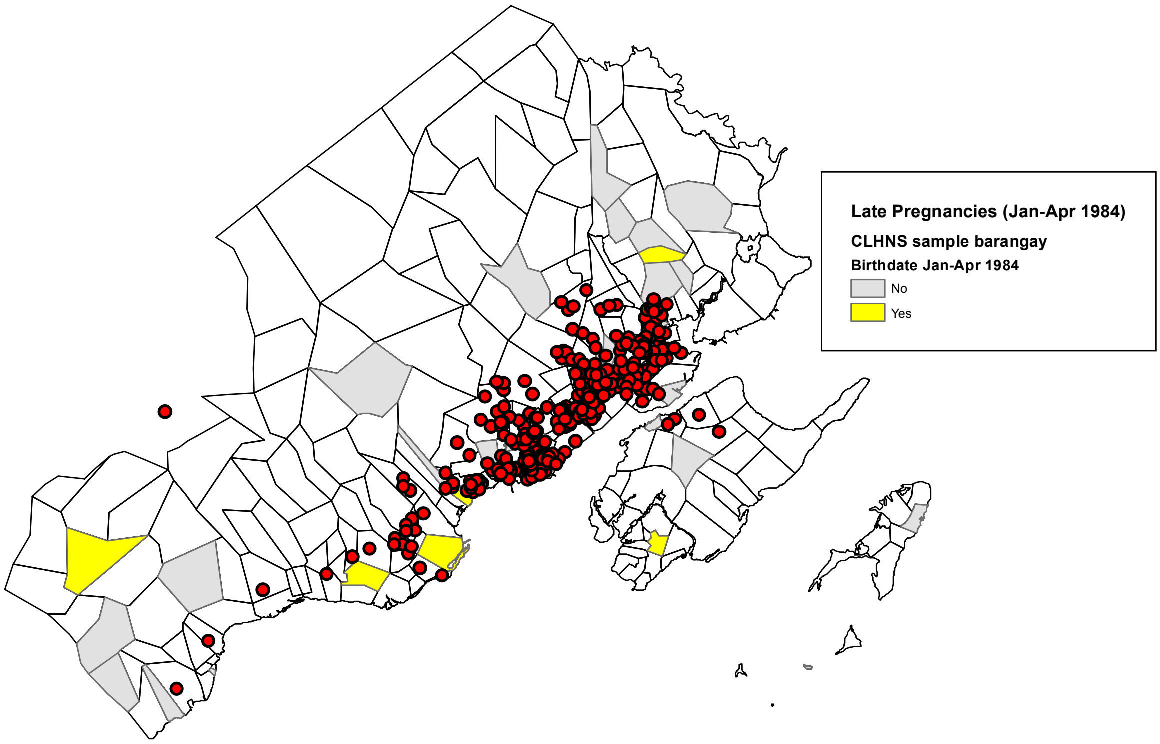

FIGURE A.3: Geographic distribution of Late-ending Pregnancies (Jan-Apr 1984)

A.3.2 Tables

Table A.17:

Height Throughout Life of Full Sample and Farm Households
Instrumented Exposure

	Birth Length Z-Score		Adult Height Z-Score	
	Full Sample	**Non-Farm HH**	**Full Sample**	**Non-Farm HH**
Fetal and Early Life Exposures				
CO, NOx, SOx, PM10	0.102	0.197	-0.121	-0.307
	(0.245)	(0.244)	(0.192)	(0.228)
Volatile Organic Compounds	-0.062	-0.090	0.134	0.377
	(0.241)	(0.257)	(0.183)	(0.240)
Heavy Metals	0.075	0.020	-0.042	0.020
	(0.076)	(0.137)	(0.054)	(0.089)
Traffic Emissions	-0.199*	-0.118	-0.009	-0.174*
	(0.103)	(0.154)	(0.073)	(0.104)
Industrial Water Emissions	0.000	-0.042	-0.081**	-0.084**
	(0.037)	(0.034)	(0.033)	(0.038)
Agricultural Pesticides	0.036	0.024	0.001	0.032
	(0.034)	(0.039)	(0.030)	(0.040)
Mining Water Emissions	-0.156***	-0.109***	-0.033	-0.057
	(0.039)	(0.040)	(0.032)	(0.039)
Other Inputs:				
Mother's Height	0.010**	0.016***	0.061***	0.066***
	(0.005)	(0.004)	(0.004)	(0.004)
Mother's Age	0.010**	0.009**	-0.001	0.003
	(0.005)	(0.004)	(0.005)	(0.005)
Father's Age	0.003	-0.000	-0.003	-0.002
	(0.004)	(0.004)	(0.004)	(0.004)
Disease Environment during Pregnancy	-0.228	-0.230*	0.016	-0.052
	(0.151)	(0.133)	(0.119)	(0.118)
Mother consumes pre-natal vitamins	0.992***	0.133***	-0.002	0.102***
	(0.233)	(0.035)	(0.196)	(0.038)
Per Capita Household Income during Pregnancy	0.001**	0.000	-0.000	-0.000
	(0.000)	(0.000)	(0.000)	(0.000)
Mother's Highest Achieved Education			0.129***	0.052***
			(0.042)	(0.012)
Per Capita Household Income at Age 1			-0.000	-0.000
			(0.000)	(0.000)
Observations (N):	3059	2,766	2129	1,895

Notes: The sample for results shown in column 1: all live-born children with recorded length measurement; column 2: all live-born children with recorded length measurement whose family cultivates at least one parcel of land at baseline; column 3: all remaining survey respondents in 2005 as well as some whose height was measured in 2002; column 4: all remaining respondents in 2005/02 whose family cultivated at least one parcel of land at baseline. Significance levels are indicated by *** 1%, ** 5%, *10%.

Table A.18:

Attrition and Early Life Exposures

	Temporary Attrition		Permanent Attrition		Attrition	
	Distance	**IV Exposure**	**Distance**	**IV Exposure**	**Distance**	**IV Exposure**
Fetal and Early Life Exposures						
CO, NOx, SOx, PM10	0.007	0.009	-0.154**	-0.044	-0.147	-0.078
	(0.068)	(0.082)	(0.073)	(0.098)	(0.104)	(0.128)
Volatile Organic Compounds	0.040	0.060	0.200***	0.081	0.240**	0.194
	(0.070)	(0.078)	(0.075)	(0.092)	(0.106)	(0.120)
Heavy Metals	0.033**	0.024	0.015	-0.043	0.047*	0.045**
	(0.016)	(0.025)	(0.020)	(0.036)	(0.028)	(0.020)
Traffic Emissions	-0.056**	-0.046	0.029	0.125***	-0.027	0.077
	(0.028)	(0.034)	(0.030)	(0.038)	(0.043)	(0.051)
Industrial Water Emissions	-0.004	-0.020	-0.004	-0.024	-0.007	-0.042
	(0.012)	(0.013)	(0.013)	(0.016)	(0.018)	(0.037)
Agricultural Pesticides	0.011	0.019	-0.002	-0.004	0.008	0.014
	(0.012)	(0.013)	(0.013)	(0.016)	(0.018)	(0.022)
Mining Water Emissions	-0.019	-0.025*	0.039***	0.029	0.032**	0.004
	(0.013)	(0.014)	(0.014)	(0.018)	(0.015)	(0.023)
Other Controls:	Yes	Yes	Yes	Yes	Yes	Yes
Observations (N):	3122	3122	3122	3122	3122	3122

Notes: Standard deviations for all regressions are clustered at the barangay level. Significance levels are indicated by *** 1%, ** 5%, *10%.

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Biography

Evan David Peet was born in American Fork, Utah on April 10, 1983. After completing high school at Lone Peak in Highland, Utah, Evan conducted a two-year volunteer mission serving an underprivileged Hispanic immigrant population. Through this experience he gained a passion for understanding and addressing issues facing the impoverished of developing nations. Afterwards, he attended Brigham Young University from 2005 to 2008 during which time he studied Economics, Mathematics and Business Management as well as working in various volunteer capacities and starting a non-profit organization based in Mexico. Evan graduated Summa cum Laude with a Bachelor of Arts in 2008 and was inducted into the Phi Kappa Phi and Golden Key honor societies.

Evan entered graduate school at Duke University in the fall of 2008 and received a Master of Arts in Economics in 2008. He is expected to obtain his Ph.D in Economics in September 2013. During his graduate studies Evan worked as a research assistant for Duncan Thomas, V. Joseph Hotz and Peter Arcidiacono. His graduate studies were supported with various financial awards from the department of Economics and the graduate school of Duke University as well as the Hewlett Institute of International Education, and the Duke Global Health Institute.

Following completion of the Ph.D., Evan will begin a position as a post-doctoral researcher in the Harvard School of Public Health in Boston, Massachusetts.